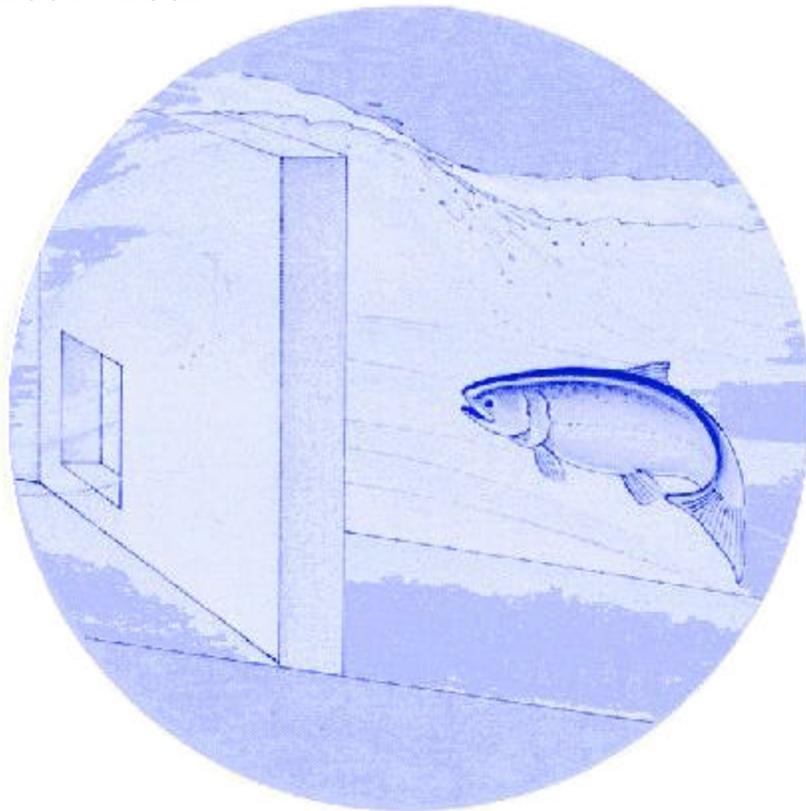


# Reproductive Ecology of Yakima River Hatchery and Wild Spring Chinook

## Yakima/Klickitat Fisheries Project Monitoring and Evaluation

Annual Report  
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Bonneville Power Administration  
P.O. Box 3621  
Portland, Oregon 97208

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**Reproductive Ecology of  
Yakima River  
Hatchery and Wild Spring Chinook**

**Annual Report 2002**

**Edited by:**

**Curtis Knudsen**

**Oncorh Consulting  
2623 Galloway SE  
Olympia, Washington 98501**

**Prepared for:**

**Washington Department of Fish and Wildlife  
600 Capitol Way North  
Olympia, Washington 98501-1091**

**Project Number 1995-064-24**

May 2003

## Executive Summary

This is the second in a series of annual and progress reports that address reproductive ecological research and comparisons of hatchery and wild origin spring chinook in the Yakima River basin. Data have been collected prior to supplementation to characterize the baseline reproductive ecology, demographics and phenotypic traits of the unsupplemented upper Yakima population, however this report focuses on data collected on hatchery and wild spring chinook returning in 2002; the second year of hatchery adult returns. This report is organized into three chapters, with a general introduction preceding the first chapter and summarizes data collected between April 1, 2002 and March 31, 2003 in the Yakima basin. Summaries of each of the chapters in this report are included below.

- **Adult traits:** Size-at-Age - Naturally spawning age-3 and age-4 hatchery fish were significantly smaller than wild fish of the same age: approximately 3 cm smaller in 3-year olds and 2 cm smaller in 4-year olds. Three- and 4-year old hatchery origin fish weighed 0.2-0.3 kg less than wild fish of the same age. In general, American River fish were larger than Naches, which were larger than upper Yakima fish. These populational differences in size-at-age are likely local adaptations developed in response to selection pressures such as migration difficulty, spawn timing, and intra-sexual competition. There was no significant Treatment effect (OCT vs SNT) on body size. Sex Ratio - The female:male (F:M) ratios of upper Yakima River wild and hatchery origin fish collected at either Roza Adult Monitoring Facility (RAMF) or on the spawning grounds as carcass samples were not significantly different. The F:M ratios of American (2.0) and Naches (2.0) spawning ground carcass samples were significantly different from the upper Yakima population (3.7) and may partially reflect between population differences in rates of nonanadromous precocial male development. Age Composition - As in previous years, the overwhelming majority of upper Yakima River wild fish returned as 4-year olds (86%) with 5% returning at age-5. Age-4 and -5 fish made up 83 and 15% of the hatchery origin returns, respectively. Age-3 jacks made up 9 and 2% of the total wild and hatchery populations, respectively. Using linear discriminant function analysis, we classified wild fish into 3-, 4- and 5-year-old ages with 98, 92, and 94% classification accuracy, respectively. Hatchery fish were classified with a separate discriminant function with 100, 100, 87, and 87% classification accuracy for 2-, 3-, 4- and 5-year olds, respectively. Based on scale sampled carcass recoveries, age composition of the American River was 1, 55 and 44% age-3, -4 and -5, respectively. Naches system fish were 1, 68 and 31% age-3, -4 and -5, respectively. In general, American River fish were older than Naches fish, and both were older than upper Yakima fish. Sexual Dimorphism - There were no significant Sex (Male vs. Female) effects detected in body size of wild or hatchery age-4 carcass recoveries in the American, Naches and upper Yakima River populations. American River and Naches age-5 fish did demonstrate significant sexual dimorphism in body size, with males larger than females. In paired length and weight samples collected from the same fish, first at RAMF and later at CESRF, fork length increased 5-6% in males and 4% in females on average, while male and female body weights decreased by 18-22% and 15-16%, respectively. POHP lengths did not differ significantly over time. Run/Spawn Timing - Mean and median passage timing of hatchery and wild fish at RAMF differed by 4 and 7 days, respectively, with wild fish passing significantly earlier

than hatchery fish. Age-5's passed RAMF earliest on average (Julian date=158), followed by age-4's (Julian date=164) and age-3's (Julian date=182). Mean and median passage timing at RAMF and mean spawn timing (Sept. 25) of both upper Yakima River hatchery and wild fish was not significantly different. Mean and median spawn timing was August 17 and 20, respectively, for the American River and September 14 and 19, respectively, for the Naches population based on carcass recoveries. The earlier American River and Naches, to a lesser degree, spawn timing is a local adaptation to cooler incubation water temperatures experienced by the higher elevation populations that require more time to accumulate sufficient temperature units to fry emergence, which is generally synchronized across all Yakima basin spring chinook populations. Carcass Recovery Bias - The F:M ratio at RAMF was significantly different from the F:M ratio of spawning ground carcass recoveries, indicating that sex ratios estimated from carcass recoveries are biased. This is because female carcasses are recovered at higher rates than male carcasses. In addition, a comparison of the proportion of age-3, -4 and -5 old fish in the RAMF sample and the carcasses recovery sample indicated that older, larger fish were recovered as carcasses at significantly higher rates than younger, smaller fish. Within age classes, the mean POHP of wild origin age-4 and age-5 carcass recoveries did not differ significantly from fish sampled at RAMF. Thus, carcass recovery length distributions do appear to accurately represent size-at-age.

- **Gametic traits:** Age-4 hatchery females (3,984 eggs) were slightly less fecund than wild origin females (4,067 eggs) based on fish collected at RAMF and spawned at CESRF. Age-5 wild origin females (4,729 eggs) were significantly more fecund on average than age-4 wild females. There was significant positive correlation between fecundity and female body size in both hatchery and wild origin age-4 females, but not age-5 females. The fecundity/length and fecundity/weight slopes of age-4 hatchery and wild origin females were not significantly different (common slopes =  $942 \text{ eggs} \cdot [\text{kg body weight}]^{-1}$  and  $145 \text{ eggs} \cdot [\text{cm POHP}]^{-1}$ ). Wild age-5 females produced approximately half as many eggs per unit increase in body weight ( $531 \text{ eggs} \cdot [\text{kg body weight}]^{-1}$  and  $77 \text{ eggs} \cdot [\text{cm POHP}]^{-1}$ ). Including body weight, mean egg weight and POHP in a multi-variate fecundity regression equation significantly increased the amount of variation explained and improved the precision of fecundity estimates. There was a significant difference between age-4 hatchery (0.180 g) and wild (0.188 g) origin mean egg weights. Age-5 wild origin females had significantly heavier eggs (0.223 g) than age-4 females. There were weak positive correlations between egg weight and female POHP and body weight, but only the wild age-4 female's was significant explaining just 2% of the total variation. The relationship between egg size and fecundity was negative, weak and significant only in wild age-4's, explaining only 13% on the total variation. Female Reproductive Effort (RE), the ratio of the weight of gametes to total body weight, of age-4 hatchery females (mean=0.198) was not significantly different than age-4 (mean=0.197) and age-5 (mean=0.179) wild females. There was no significant difference in viability of eggs of hatchery (mean viability =0.91) and wild (mean viability =0.91) origin fish. Hatchery age-4 females had Relative Fecundity (RF) values that were lower, but not significantly different from wild females (Wild RF=  $1049 \text{ eggs} \cdot (\text{kg body weight})^{-1}$ ; Hatchery RF=  $1089 \text{ eggs} \cdot (\text{kg body weight})^{-1}$ ), but wild age-5 female's (mean RF  $807 \text{ eggs} \cdot (\text{kg body weight})^{-1}$ ) were significantly lower than both age-4 females. Both hatchery (mean=0.003) and wild (mean=0.004) origin females had very low proportions of abnormally developing fry, and the proportions were not significantly different. There was no significant difference between

wild and hatchery origin fry fork lengths or body weights at the “button up” stage. There were strong positive relationships between fry size and egg weight for both wild and hatchery origin females.

- **In-river Redd Characteristics:** We monitored the in-river redd characteristics of naturally spawning upper Yakima River hatchery and wild females. Redds were sampled by snorkeling 3 to 4 days per week between September 9 and October 2 and were associated with a female of known origin identified by the presence (wild) or absence (hatchery) of the female’s adipose fin. After spawning was completed, a suite of redd width, length, depth, velocity and substrate parameters were collected from each known-origin redd. A total of 76 hatchery- and 43 wild-origin females and associated redds were monitored. Naturally spawning hatchery females were significantly smaller ( $p=0.01$ ) than wild females by 1.7 cm on average. In our preliminary analyses of redd parameter data there were no significant differences in either redd width or length dimensions, water depth, velocities or substrate characteristics between hatchery- and wild-origin females ( $p>0.45$ ). Redd characteristics were generally not correlated with female length and in the 8 significant correlations out of 44, female length only explained between 6 and 20% of the total variation. We will use this data to examine sample size needs and sampling effort for next year’s work.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

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## General Introduction

This report is intended to satisfy two concurrent needs: 1) provide a contract deliverable from Oncorh Consulting to the Washington Department of Fish and Wildlife (WDFW), with emphasis on identification of salient results of value to ongoing Yakima/Klickitat Fisheries Project (YKFP) planning, and 2) summarize results of research that have broader scientific relevance. This is the second in a series of reports that address reproductive ecological research and monitoring of spring chinook in the Yakima River basin. In addition to within-year comparisons, between-year comparisons will be made to determine if traits of the wild Naches basin control population, the naturally spawning population in the upper Yakima River and the hatchery control population are diverging over time. This annual report summarizes data collected between April 1, 2002 and March 31, 2003. In the future, these data will be compared to previous years to identify general trends and make preliminary comparisons.

Supplementation success in the Yakima Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program is defined as increasing natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack et al. 1997). Within this context demographics, phenotypic traits, and reproductive ecology have significance because they directly affect natural productivity. In addition, significant changes in locally adapted traits due to hatchery influence, i.e. domestication, would likely be maladaptive resulting in reduced population productivity and fitness (Taylor 1991; Hard 1995). Thus, there is a need to study demographic and phenotypic traits in the YKFP in order to understand hatchery and wild population productivity, reproductive ecology, and the effects of domestication (Busack et al. 1997). Tracking trends in these traits over time is also a critical aspect of domestication monitoring (Busack et al. 2002) to determine whether trait changes have a genetic component and, if so, are they within acceptable limits. Each chapter of this report deals with monitoring phenotypic and demographic traits of Yakima River basin spring chinook comparing hatchery and wild returns in 2002; the second year of adult hatchery returns. The first chapter deals specifically with adult traits of American River, Naches basin (excluding the American River), and upper Yakima River spring chinook, excluding gametes. The second chapter examines the gametic traits and progeny produced by upper Yakima River wild and hatchery origin fish. In the third chapter, we describe work begun initially in 2002 to characterize and compare redds of naturally spawning wild and hatchery fish in the upper Yakima River.

The chapters in this report are in various stages of development and should be considered preliminary unless they have been published in a peer-reviewed journal. Additional fieldwork and/or analysis is in progress for topics covered in this report. Readers are cautioned that any preliminary conclusions are subject to future revision as more data and analytical results become available.

## Acknowledgments

We would like to thank Bonneville Power Administration for financially supporting this work. In addition, we could not have completed this work without the help and support of many individuals during 2002/2003. We have tried to recognize each of them either on title pages or in acknowledgments within each chapter of this report.

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# Chapter 1

## Monitoring Phenotypic and Demographic Traits of Yakima River Hatchery and Wild Spring Chinook: Spawner Traits

Prepared by:

Curtis M. Knudsen<sup>1</sup>, Steve L. Schroder<sup>2</sup>, Mark V. Johnston<sup>3</sup>, Todd N. Pearsons<sup>4</sup>,  
Jason A. Rau<sup>5</sup>, Charles R. Strom<sup>5</sup> and Mike L. Hamlin<sup>4</sup>

<sup>1</sup> Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

<sup>2</sup> Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501-1091

<sup>3</sup> Yakama Nation, P.O. Box 151, Toppenish, WA 98948

<sup>4</sup> Washington Department of Fish and Wildlife, 201 N. Pearl Street, Ellensburg, WA 98926

<sup>5</sup> Yakama Nation, Cle Elum Supplementation and Research Facility, Cle Elum, WA 98922

## Abstract

A major component of determining supplementation success in the Yakima Klickitat Fishery Project's spring chinook (*Oncorhynchus tshawytscha*) program is an increase in natural production. Within this context, comparing upper Yakima River hatchery and wild origin fish across traits such as sex ratio, age composition, size-at-age, fecundity, and run timing is important because these traits directly affect population productivity and individual fish fitness which determine a population's productivity. In addition, comparisons of these traits across the three putative wild populations in the Yakima River basin: American River, Naches, and upper Yakima River, help us identify and understand how local adaptations have uniquely shaped each population.

**Sex Ratio** - The female:male (F:M) ratios of upper Yakima River wild (1.8) and hatchery (2.6) origin fish collected at Roza Adult Monitoring Facility (RAMF) were not significantly different. The F:M ratios of wild and hatchery origin fish in the spawning ground carcass sample were 3.8 and 3.6, respectively, and were also not significantly different. The F:M ratios of American (2.0) and Naches (2.0) spawning ground carcass samples were significantly different from the upper Yakima population and may reflect between population differences in rates of nonanadromous precocial male development. Visual sexing of fish at RAMF identified females more accurately (93% correct) than males (70% correct) resulting in a significant overestimate of the proportion of returning females

**Age Composition** – In 2002 the overwhelming majority of upper Yakima wild fish returned as 4-year olds (86%) with 5% returning at age-5. Age-4 fish made up 86% of the total hatchery origin returns. Age-3 jacks made up 9 and 2% of the total wild and hatchery populations, respectively. Linear discriminant function analysis was used to classify wild upper Yakima fish into 3-, 4- and 5-year-old age classes with 98, 92, and 94% classification accuracy, respectively. Hatchery fish were classified with a separate discriminant function with 100, 100, 87, and 87% classification accuracy for 2-, 3-, 4- and 5-year olds, respectively. Based on scale sampled carcass recoveries, age composition of the American River was 1, 55 and 44% age-3, -4 and -5, respectively. Naches system fish were 1, 68 and 31% age-3, -4 and -5, respectively.

**Sexual Dimorphism** – In 2002 there were no significant Sex (Male vs. Female) effects detected in body size of wild or hatchery age-4 American, Naches or upper Yakima River populations. American River and Naches age-5 fish did demonstrate significant sexual dimorphism. In both populations, mean male POHP length was significantly greater than female length. Paired length and weight samples from fish sampled first at RAMF and then 1-5 months later at CESRF, were compared. POHP lengths did not differ significantly between samples, but fork length increased significantly (5-6% in males and 4% in females) and body weight decreased significantly: 18 to 22% and 15 to 16% in males and females, respectively.

**Size-at-Age** – Just as in 2001, returning hatchery fish in 2002 were significantly smaller than wild fish of the same age. Four-year old hatchery fish were 1.8 cm smaller than wild origin fish. Three-year old hatchery fish were 3.0 cm smaller than wild fish. Both 3- and 4-year old hatchery origin fish weighed 0.2-0.3 kg less than wild fish of the same age. There was no significant within-age difference in body size of age-2, -3, -4 or -5 OCT and SNT returns. Age-4 and -5 fish from the American River were generally larger than the Naches fish, which in turn were larger than upper Yakima fish of the same age. These wild origin populational differences in size-at-age are likely local adaptations developed in response to population-specific selection pressure from factors such as migration difficulty (gradient and flow), water temperature, and intra-sexual competition.

**Run/Spawn Timing** - Mean and median passage timing of hatchery and wild fish at RAMF differed by 4 and 7 days, respectively, with wild fish passing significantly earlier than hatchery fish. Age-5's passed RAMF earliest on average (Julian date=158), followed by age-4's (Julian date=164) and age-3's (Julian date=182). OCT and SNT hatchery groups did not differ significantly in passage timing at RAMF. Mean spawn timing of both upper Yakima River hatchery and wild fish, based on in-river carcass recoveries, was Sept. 25 and there was no significant difference in temporal distributions of recoveries. Neither wild nor hatchery origin fish exhibited a significant linear relationship between passage date at RAMF and date of spawning at CESRF in 2002. Mean and median spawn timing was August 17 and 20, respectively, for the American River and September 14 and 19, respectively, for the Naches population based on carcass recoveries. The spawn timing of each population is likely a local adaptation in response to water temperatures during incubation. American, and to a lesser extent Naches, fish experience cooler water temperatures because of their higher elevation spawning habitat. Since fry emergence occurs in synchrony across all Yakima River populations, the higher elevation populations must spawn earlier in order for eggs to accumulate sufficient temperature units to emerge at the appropriate time.

**Carcass Recovery Bias** - The F:M ratio at RAMF was significantly lower than the F:M ratio of spawning ground carcass recoveries, indicating that sex ratios estimated from carcass recoveries are biased due to female carcasses being recovered at higher rates than male carcasses. A comparison of the proportion of age-3, -4 and -5 old fish in the RAMF sample and the carcasses recovery sample also indicated that older, larger fish were recovered as carcasses at significantly higher rates than younger, smaller fish. Within age classes, the mean POHP of carcass recoveries did not differ significantly from fish sampled at RAMF. Thus, carcass recovery length distributions do appear to accurately represent size-at-age.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

## Introduction

Supplementation success in the Yakima Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program has been defined as an increase in natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack et al. 1997). Heritable quantitative traits, such as body size and size-at-age, are important to monitoring because these traits reflect local adaptations made by each population to selection pressures from their environment and bears directly on each population's productivity and fitness.

Changes in phenotypic and demographic traits due to hatchery influences (domestication) can have a genetic or environmental cause or be a complex combination of both (Hard 1995; Kinnison et al 2001; Quinn et al. 2001; Su et al. 2002). Significant changes in locally adapted traits due to domestication would likely be maladaptive in the wild, reducing reproductive success resulting in lower population productivity and fitness (Taylor 1991; Fleming and Gross 1993; Hard 1995; Fleming and Petersson 2001; Lynch and O'Hely 2001). A change in a trait that is random with respect to any heritable trait's distribution but results in a reduction in fitness, will not generate a genetic response in subsequent generations and population fitness is reduced for only a single generation. The progeny produced from naturally spawning cultured fish should suffer no reduction in reproductive success when they spawn. Irrespective of underlying causes, body size affects a female's ability to compete in the wild for nest sites and construct and guard redds (Schroder 1982; van den Berghe and Gross 1984; van den Berghe and Gross 1989; Foote 1990), influences redd vulnerability to scour during flood events (van den Berghe and Gross 1989; Steen and Quinn 1999) and directly influences fecundity (Fleming and Gross 1990; Beacham and Murray 1993; Knudsen et. 2002). Body size can also influence spawning distribution by affecting the ability of fish to colonize more distant or higher elevation spawning areas (Beacham and Murray 1993; Kinnison et al. 2001) and larger portions of river systems (Rogers 1987; Blair et al. 1993; Hendry and Quinn 1997). Lower mean body weight can reduce the average carcass biomass returning to the natal basin, reducing exogenous nutrients utilized by rearing juveniles (Bilby et al. 1996). Changes in demographic/life history traits, such as a reduction in age classes or sex ratio, also have direct impacts, reducing a population's phenotypic variation, total annual egg production and effective size (Nunney 1991). In addition, significant changes in spawn timing can shift fry emergence timing outside the locally adapted temporal window resulting in reduced fry survival (Brannon 1987; Beacham and Murray 1993; Quinn et al. 1995; Hendry et al. 1998; Smoker et al. 1998; Beer and Anderson 2001; Quinn et al. 2002).

Hatchery origin Pacific salmon have been shown to exhibit lower reproductive success than wild fish in some studies (Resenbichler and McIntyre 1977; Chilcote et al. 1986; Leider et al. 1990; Fleming and Gross 1992, 1993). Documenting changes in traits related to productivity and fitness, whether genetically or environmentally driven, contributes to our understanding of the immediate impacts of supplementation. In addition, tracking trends in these traits over time is an important aspect of the YKFP's

domestication selection monitoring effort (Busack et al. 2002) designed to determine whether there is a significant genetic component in observed trait changes.

We begin this report by describing three sets of biological data collected from hatchery and wild origin spring chinook returning to the upper Yakima River and describe changes in length and body weight due to secondary sexual development between passage at RAMF and spawning, analyze sexing accuracy at RAMF and compare estimated sex ratios. Next, we compare hatchery and wild origin fish returning in 2002 over the following traits: age composition, size-at-age, passage timing at RAMF, and spawning timing as represented by the temporal distributions in carcass recoveries. We also make comparisons of age composition, size-at-age, and spawning timing between upper Yakima River, Naches, and American River wild spring chinook populations. Finally, we examined bias in carcass recovery samples. In the second chapter of this report, we compare the reproductive traits, gametes, and progeny produced from hatchery and wild origin upper Yakima River spring chinook returning in 2002. A future report will compare wild origin samples representing the historical baseline years 1997-2000 to hatchery and wild origin samples from supplemented return years.

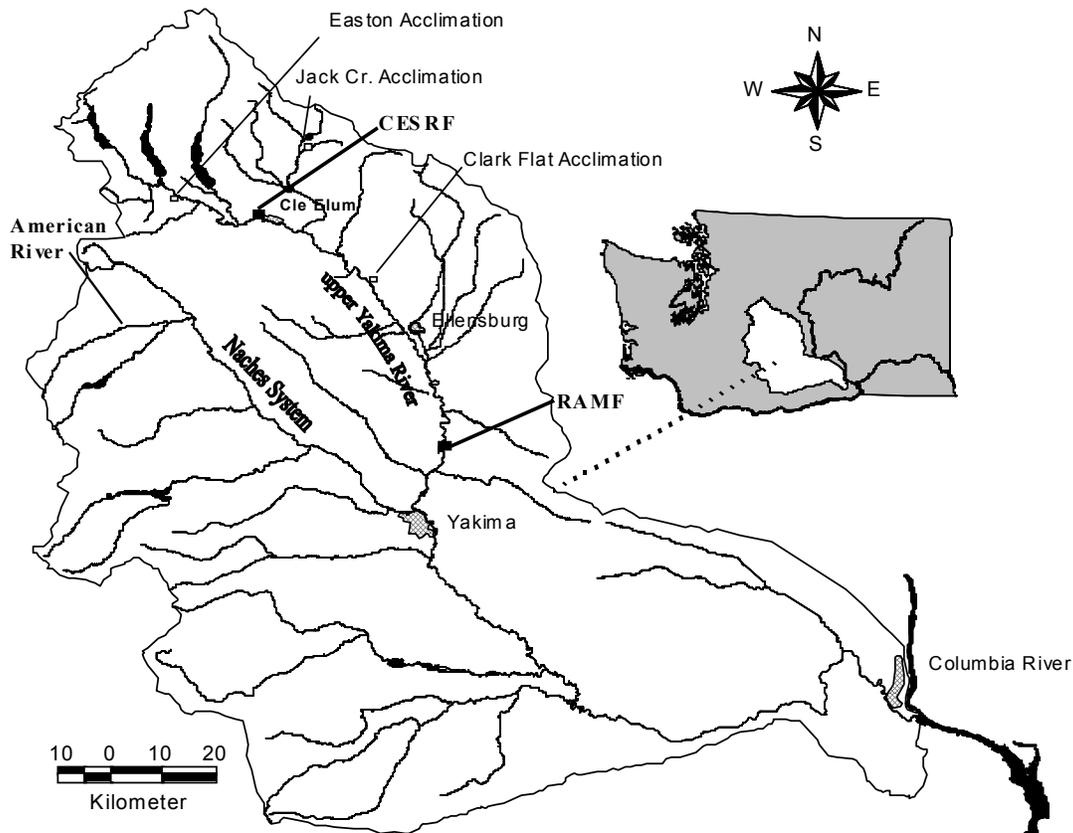
## **Methods and Materials**

### **Study Populations**

Three genetically distinct wild spring chinook substocks have been identified in the Yakima River basin (Busack and Marshall 1991; unpublished DNA analyses by WDFW's Genetics Lab, S. Young): the upper Yakima River, Naches system (including the Naches River, Little Naches River, Rattlesnake River and Bumping River) and the American River (a tributary of the Naches River) (Fig. 1). These three populations have also exhibit differences in life history and demographic traits (Major and Mighell 1969; Fast et al. 1991; Knudsen 1991; Knudsen et al. 2002). The following analyses focus primarily on the upper Yakima River population spawning upstream of RAMF, the population targeted for supplementation under the YKFP (Busack et al. 1997), but also includes comparisons between the upper Yakima, American and Naches populations. The age-4 component of the Naches population has been proposed as a wild control population for the YKFP's Domestication Monitoring Program (Busack et al. 2002).

There are three sets of biological data collected from spring chinook returning to the upper Yakima River above RAMF. The first set represents hatchery origin fish sampled as they pass upstream through RAMF. After sampling, these fish are immediately released back into the river to complete their spawning migration. The second set represents both hatchery and wild origin fish collected at RAMF for use at the Cle Elum Supplementation and Research Facility (CESRF) as either broodstock or experimental subjects in reproductive success studies. These fish are referred to as the CESRF samples and were initially sampled at RAMF and then held to maturity at CESRF where they were again sampled at spawning. The third dataset represents in-river carcass recoveries of hatchery and wild origin fish collected on the spawning grounds over the

course of the spawning season. All data representing the American River and Naches populations come from spawning ground carcass recoveries.



**Figure 1. Yakima River basin showing the upper Yakima River, Roza Adult Monitoring Facility (RAMF), the Cle Elum Supplementation Research Facility (CESRF), Naches system and American River.**

### Hatchery Fish at RAMF

The largest and most comprehensive sampling of upper Yakima hatchery spring chinook occurs at RAMF as fish move upstream between April and September (Sampson and Fast 2001). Data from these hatchery origin fish are used to represent the population's age composition, size-at-age, and run timing at RAMF. Hatchery origin fish are identified as they pass through RAMF either by the presence of a Coded-Wire Tag (CWT), which activates a sensor tripping a hydraulic gate, or by the visual identification of the missing clipped adipose fin. All hatchery juvenile releases were adipose fin clipped and tagged with at least one CWT. During 2002, 6,378 of the 6,384 hatchery origin fish age-3 or older passing RAMF were sampled for mark type and date of passage recorded. Of these hatchery fish, 1,621 (25%) were sampled for length (Fork Length [FL] and Post-Orbital-to-Hypural Plate [POHP]), body weight data and had a scale

collected for aging. Each fish was classified to sex by visual inspection. After being sampled, all but 199 hatchery fish (3% of the total run) were released back into the river to spawn naturally. Those not released were transported to CESRF and used as broodstock in a newly established hatchery control line or used in reproductive success studies comparing hatchery and wild origin fish (Knudsen et al. 2003; Schroder et al. 2003). In addition, 475 hatchery origin age-2 fish (precocious males) released as smolts in the spring of 2002 were length and weight sampled in the late summer/fall as they passed upstream through RAMF.

### Hatchery and Wild Origin Fish Held at CESRF

From 1997 to 2001, only wild origin fish were collected at RAMF for broodstock. Data collected from these wild origin fish are used to represent the wild population's age composition, size-at-age, sex ratio, run timing at RAMF and spawn timing. The estimated total number of broodstock needed for full hatchery production is based on the mean historical sex ratio, age composition, age-specific fecundity while fish are held, adult pre-spawning mortality, BKD infection rates, and in-culture egg-to-smolt survival. Broodstock are selected at RAMF randomly with respect to sex. A fixed proportion of the total broodstock is collected each week over the entire run based on weekly mean historical passage proportions at RAMF with the first week beginning on the day the first fish passes RAMF. Using this methodology, broodstock take is allocated over the entire run, weighted by historical passage timing. This ensures that significant over- and under-collecting of broodstock does not occur, as can happen when the broodstock collection goal is a fixed percentage of the predicted run and actual run size significantly deviates from the prediction. Weekly wild-origin broodstock collections in 2002 were made over 4 days within each week when 9 or more fish were collected. When weekly collections were less than 9 fish, they occurred over 1-3 days. As long as the current year's run does not deviate significantly from historical run timing trends, broodstock collections will be well represented over the entire run. Weekly broodstock collections during 2002 and the mean historical passage profile (1983-2001) are shown in Figure 2. The wild-origin run was generally similar to the historical run, although several distinct peaks and troughs in the 2002 run were "smoothed" out in the historical trend. The hatchery run followed the wild run generally, but had a lower early peak and higher second peak. However, hatchery fish collected for use at CESRF were underrepresented in the initial peak of the run and over-represented in the latter portion of the run (Fig. 2).

Collection of wild origin age-3 jacks for broodstock is handled differently than adults. The proportion of jacks collected for broodstock is based on the historical geometric mean proportion of jacks returning within a cohort. There are significant differences in size between age-3 and age-4 fish and it is possible to separate age-3 and -4 fish with 4% error or less at RAMF based on POHP length and body weight (Knudsen et al. 2002; see analyses below). The estimated proportion of wild jacks returning is based on length criteria visually estimated as fish pass RAMF. There is an unknown amount of error involved in this estimation technique due to the short time fish are observed as they pass down an inclined chute and no rigorous test of this method has occurred. Additional jacks beyond those needed for broodstock were collected in 2002

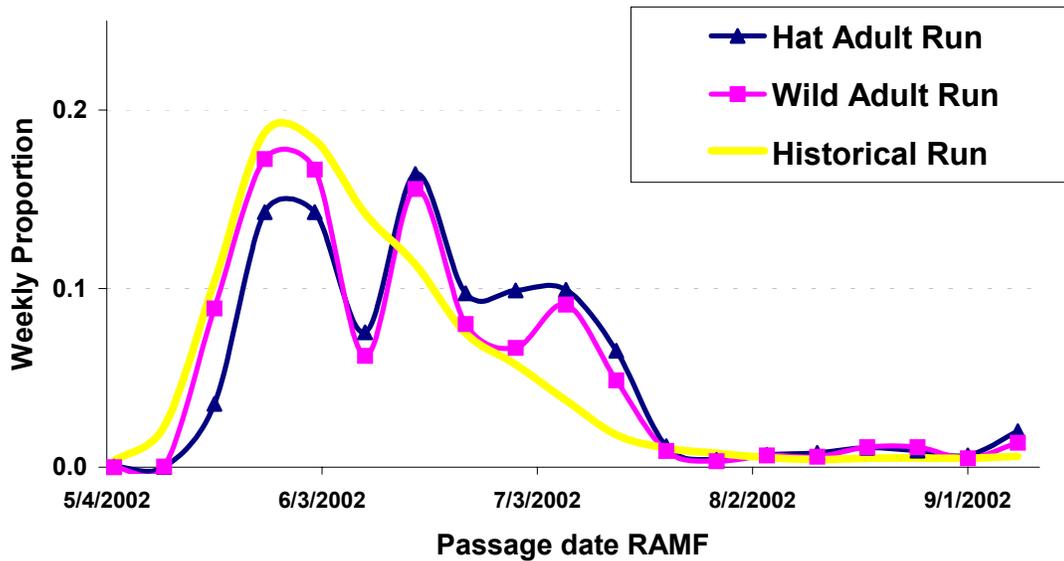


Figure 2. Weekly run timing in 2002 and historical (1983-2001) run timing (solid line). Historical run values are the weekly proportion of the run passing RAMF based on mean historical run sizes. The “Hat Adult Run” and “Wild Adult Run” values are the weekly proportions of hatchery (▲) and wild (■) fish passing RAMF in 2002.

for use in reproductive success studies at CESRF.

Biological sampling of the wild origin CESRF sample at RAMF included length (FL and POHP), body weight, scale samples, passage date and a provisional visual sex classification. In addition, all fish transported to CESRF (either hatchery and wild) are tagged intramuscularly in the pelvic girdle with a uniquely coded 18 mm Passive Integrated Transponder (PIT) tag (Johnston and McCutcheon *in prep.*) and their history from the time of capture through pre-spawning mortality or successful spawning is tracked. At spawning, length (FL and POHP), body weight, and the sex of each fish are again recorded. This data, along with gametic traits collected during spawning, can then be linked back to that fish’s biological data collected at RAMF.

Artificial spawning at CESRF occurred over a five-week period from September 4<sup>th</sup> through October 8<sup>th</sup>. Additional wild and hatchery origin fish collected at RAMF for use in reproductive success studies or that died prior to spawning, were sampled in the same manner as broodstock and are included in the age composition, sex ratio and size-at-age analyses below, as appropriate. In 2002, 631 wild- and 199 hatchery-origin fish were collected for both broodstock and reproductive success studies.

#### Hatchery and Wild In-river Carcass Recoveries

The third dataset is made up of hatchery and wild origin carcasses recovered by YN personnel during the course of weekly spawning ground surveys made throughout the Yakima River basin between July and October (Sampson and Fast 2001). Origin

(hatchery/wild based on the presence of marks), recovery date and stream reach are recorded for each carcass sampled. Sex, length (FL and POHP) and age (scale samples) are collected on a subsample of carcasses. In 2002, carcasses were recovered in the American River between July 31 and September 4 (n=181), in the Naches system between August 13 and September 21 (n=154), and between September 11 and October 4 in the upper Yakima River (n=42 wild- and n=114 hatchery-origin). Comparisons of spawn timing, as represented by carcass recoveries, were made using ANOVA. Additional sampling of carcasses in the upper Yakima River was conducted by National Marine Fisheries Service personnel between September 25 and October 10, 2002 in order to estimate spatial and temporal distribution of hatchery spawners (A. Dittman, NMFS, pers. comm.). None of the NMFS carcass data is included in this report.

## Traits

### Sex Ratio

Estimates of Female:Male (F:M) ratios were calculated based on fish collected at RAMF (excluding jacks) and held at the CESRF facility. The sex of these fish could be identified unambiguously by *post mortem* inspection of the body cavity. In addition, the accuracy of RAMF visual sex classifications of live fish, made 1-5 months prior to spawning, were determined by comparing them to the CESRF *post mortem* sexing of the same fish identified by the PIT tag codes. Comparisons of sex ratios between groups were made using a  $\chi^2$ -test.

### Age Composition

Ageable scale samples were collected from 1,621 fish age-3 or greater passing RAMF in 2002. Scales were placed on gummed cards and labeled so that the PIT tag number and other biological data collected could be linked to the fish's age. Ages are designated as the number of years from the year of conception (broodyear) to return year. Thus, a fish produced from parents spawning in the fall of 1998 and returning in 2002 is designated an age-4 fish. Under this convention, precocious males (nonanadromous males maturing in their first [wild only] or second [wild and hatchery] year) are designated age-1 and age-2, respectively. Age composition of the wild adult ( $\geq$  age-4) population was estimated from fish held at CESRF (n=631 of which 52 could not be aged), while the wild age-3 jack proportion was estimated based on visual estimations of length as fish passed RAMF. Acetate impressions were made from the scale cards and ages determined by examining the impressions using a microfiche reader. Two scale analysts: T. Swan, YN, and J. Sneva, WDFW, independently aged all scales. In-river wild origin carcass samples, in which the sex of fish was confirmed by examining body cavities, were compared to wild origin samples collected at RAMF using a  $\chi^2$ -test to determine whether there was bias caused by unequal carcass recovery rates of different age classes and sexes. Age compositions of Naches system (n=154) and American River (n=181) populations were estimated from scale sampled carcass recoveries.

## Sexual Dimorphism in Body Size and Development of Secondary Sex Characteristics

Sexual dimorphism in body size has often been observed in Pacific salmon (e.g. Quinn and Foote 1994; Knapp and Vrendenburg 1996; Knudsen et al. in prep.) and can be an indicator of the intensity of sexual selection, particularly in males (Fleming and Gross 1994). However, it can also be strongly affected by selection from size and sex selective fisheries (Beaty 1996; Hamon et al. 2000; Knudsen et al. in prep.). We examined the 2002 CESRF data set (sex confirmed by *post mortem* inspection) and compared length (POHP) and body weight differences between upper Yakima River age-4 and age-5 adults due to Sex (Male vs. Female) effects using a 1-way ANOVA. The two age classes were analyzed separately based on results from 2001 showing only age-5 fish had a significant Sex effect (Knudsen et al. 2002). If no significant Sex effect was observed, then body size data were pooled across sexes in subsequent analyses. In addition, we compared the 2001 and 2002 returns (hatchery and wild origin ages 3 and 4) to determine if the same trends in size-at-age had occurred in both return years. To do this, we used a 3-way ANOVA testing for Year (2001 vs 2002), Origin (Hatchery vs Wild), and Age (3 vs 4) effects, including all interactions. We also analyzed age-4 and – 5 carcass recoveries from Naches system and American River wild populations for sexual dimorphism. In those analyses, we used a 2-way ANOVA to estimate Age (4 vs. 5), Sex (Male vs. Female) and Interaction effects. In some ANOVA's we made multiple comparisons between groups using the Tukey multiple-comparisons test (Zar 1984).

After entering the Columbia River, maturing spring chinook stop feeding and must rely on endogenous energy stores to sustain themselves. This, along with the development of secondary sexual traits and gametes, causes morphological changes in fish over time. We estimated to what extent upper Yakima River spring chinook body size changes between the time they pass RAMF and spawn by comparing the length and body weight of fish sampled when they passed RAMF and then again, 1 to 5 months later, when spawned at CESRF using a paired-sample t-test.

### Size-at-Age

We used the RAMF or CESRF (in cases where sex effects were significant) samples to compare hatchery and wild size-at-age using ANOVA and made comparisons between 2001 and 2002 returns. In addition, the accuracy with which age could be estimated was calculated from separate linear discriminant function analyses (Fisher 1936) of wild origin and hatchery-origin fish, using log transformed POHP lengths and body weights collected at RAMF as classification variables. Model significance was estimated using MANOVA and classification accuracy was estimated using a jackknife classification procedure (Efron 1982).

Length distributions of American, Naches and upper Yakima wild population carcass recoveries were compared using 2-way ANOVA estimating Age (4 vs 5) and Population (American vs Naches vs upper Yakima) effects.

## Run/Spawn Timing

We examined the linear relationship between the date wild origin fish were collected at RAMF and the date they were subsequently spawned at CESRF by regressing passage date at RAMF against spawning date at CESRF in 2002. The RAMF cumulative passage timing distributions of hatchery and wild origin fish were compared using a Kruskal-Wallis non-parametric ANOVA (K-W test; Zar 1984). Within hatchery fish, passage timing of the OCT and SNT treatment groups at RAMF were also compared with a K-W test.

## Carcass Recovery Bias

RAMF samples are randomly collected from throughout the run (Fig. 2) and should be representative of hatchery and wild origin fish naturally spawning above RAMF. If naturally spawning fish of different ages, sizes and sex are equally likely to be recovered as carcasses, then the proportion of fish in each sex/age class observed at the non-selective RAMF trap should be equal to the proportions observed in the carcass recovery sample. If carcass recovery rates are not equal across size and sex, age composition and sex ratio estimates will be biased. We estimated whether bias occurred in 2002 upper Yakima spring chinook by comparing size-at-age, age composition and the F:M ratio of fish passed upstream at RAMF to estimates generated from in-river carcasses recoveries made 1 to 5 months later using  $\chi^2$  analysis.

All statistical analyses were done using the SYSTAT 8.0 software package (SPSS 1998).

# Results

## Sex Ratio

### Accuracy of Visual Sexing at RAMF

Table 1 shows the overall classification accuracy of visually sexing fish at RAMF in 2002. As in past years, females are more accurately identified (93% correctly identified) than males (70% correctly identified). This creates bias in sex ratios by over estimating the proportion of females. Inaccurate sexing also creates problems when analyzing traits of individual fish in which sex can be an important covariate, such as age, size, and potential egg deposition. However, for traits that are independent of sex it can be advantageous to increase sample sizes by using the much larger, more comprehensive RAMF dataset (over an order of magnitude larger than the CESRF hatchery origin dataset) and pooling over sexes.

Table 1. Classification matrix showing the accuracy of sex identifications at RAMF in 2002 based on visual classification of fish. Each cell shows the number of fish of known sex ("Correct sex" determined from carcasses) that were classified as male or female (Classification result). The percentage of fish classified into each category is in parentheses. Overall Mean Accuracy is the mean of the Percentage Correctly Classified as male and female.

| Correct sex           | Classification result |             | Percentage correctly classified |
|-----------------------|-----------------------|-------------|---------------------------------|
|                       | Male                  | Female      |                                 |
| Male                  | 105 (69.5%)           | 46 (30.6%)  | 69.5%                           |
| Female                | 25 ( 7.5%)            | 308 (92.5%) | 92.5%                           |
| Overall mean accuracy |                       |             | 81.0%                           |

### CESRF and Spawning Ground Sex Ratios

The F:M ratios of wild (1.8) and hatchery (2.6) origin fish in the CESRF sample (hatchery n=100; wild n=409) were not significantly different ( $X^2=2.03$  with Yates correction; df=1; p=0.154). Percentages by sex are given in Table 2. In the spawning ground samples, the F:M ratios of wild and hatchery origin fish were 3.8 and 3.6, respectively, and were not significantly different ( $X^2=0.067$  with Yates correction; df=1; p=0.914). American (1.97) and Naches (1.96) F:M ratios were not significantly different, while the upper Yakima (hatchery and wild combined 3.62) was ( $X^2=7094$ ; df=2; p=0.029), having almost twice as many female carcasses recovered per male.

Table 2. Sex ratios estimated for upper Yakima River hatchery and wild populations in 2002 from carcass recoveries by YN personnel and from fish collected at RAMF and held at CESRF. Sex was identified by *post mortem* inspections.

|               |          | Male - n (%)       | Female - n (%) |
|---------------|----------|--------------------|----------------|
|               |          | Carcass recoveries | Hatchery       |
|               | Wild     | 9 (23.1)           | 30 (76.9)      |
| CESRF Samples | Hatchery | 28 (28.0)          | 72 (72.0)      |
|               | Wild     | 148 (36.2)         | 261 (63.8)     |

### Age Composition

#### Upper Yakima River Wild Origin

Age composition of adult (age-4 and older) wild origin fish was estimated from fish selected at RAMF and held until mature at CESRF (n=482). This includes fish selected for broodstock. These fish were sexed *post mortem* and parsed into age classes by sex (Table 3). As in previous years, the overwhelming majority of wild origin fish (86%) returned as 4-year olds with 5% returning at age-5. Jacks made up the remaining 9% of the wild population. Hatchery fish were also predominately age-4 (83%), but had a higher percentage of age-5's (15%) and fewer age-3's (2%) than wild fish. Wild origin spawning ground carcass recoveries (n=39 aged fish) were also used to generate age composition estimates by sex (Table 6). Age-3 fish made up only 2%, age-4's 83 % and

age-5's 15% of the carcass sample. Only one out of 482 wild origin anadromous returns sampled in 2002 was not aged as a yearling outmigrant (stream type). It had migrated as a 0-age smolt.

| Origin                    | Age | Overall %        | % Male (n) | % Female (n) |
|---------------------------|-----|------------------|------------|--------------|
| Upper Yakima River Wild   | 3   | 9.1 ( 44)        | 8.9 ( 43)  | 0.2 ( 1)     |
|                           | 4   | 86.1 (414)       | 29.5 (142) | 56.5 (272)   |
|                           | 5   | 4.8 ( 23)        | 2.1 ( 10)  | 2.7 ( 13)    |
| Up. Yakima River Hatchery | 3   | 1.7 <sup>a</sup> | 1.7        | 0.0          |
|                           | 4   | 83.4 (5317)      | 25.7 ( 33) | 56.8 ( 73)   |
|                           | 5   | 14.8 ( 952)      | 0.0 ( 0)   | 14.9 ( 2)    |

<sup>a</sup> Hatchery jack proportions based on visual estimates of length as fish pass RAMF and assumes all jacks are male. Other wild age percentages are adjusted to include jacks.

Linear discriminant function analysis was used to estimate the accuracy with which wild and hatchery origin fish of known age (based on scales) could be classified. Log transformed POHP length and body weight of fish collected at RAMF were used to classify fish into age classes (MANOVA; 6, 760 df;  $p < 0.001$ ). Males and females were pooled within each age class. Jackknifed classification accuracies for wild origin fish were 98, 92, and 94% for 3-, 4- and 5-year olds, respectively (Table 4; Fig. 3), with the majority of errors occurring between age-4 and -5 classes. Jackknifed classification accuracies for hatchery origin fish were 100, 100, 87, and 87% for 2-, 3-, 4- and 5-year olds, respectively (Table 5; Fig. 4; MANOVA; 6, 176 df;  $p < 0.001$ ). Variation in body size, particularly body weight, increased with age causing heteroscedasticity. Log transformations were used to correct for unequal between-group variances so that the assumption of equal between-group variance-covariance matrices would not be violated.

| Known age             | Age classification – N (%) |             |             | Percent correctly classified |
|-----------------------|----------------------------|-------------|-------------|------------------------------|
|                       | Age 3                      | Age 4       | Age 5       |                              |
| Age 3                 | 44 (97.8%)                 | 1 ( 2.2%)   | 0 ( 0.0%)   | 97.8%                        |
| Age 4                 | 4 ( 0.7%)                  | 490 (91.6%) | 41 ( 7.7%)  | 91.6%                        |
| Age 5                 | 0 ( 0.0%)                  | 0 ( 0.0%)   | 31 (100.0%) | 94.2%                        |
| Overall mean accuracy |                            |             |             | 94.5%                        |

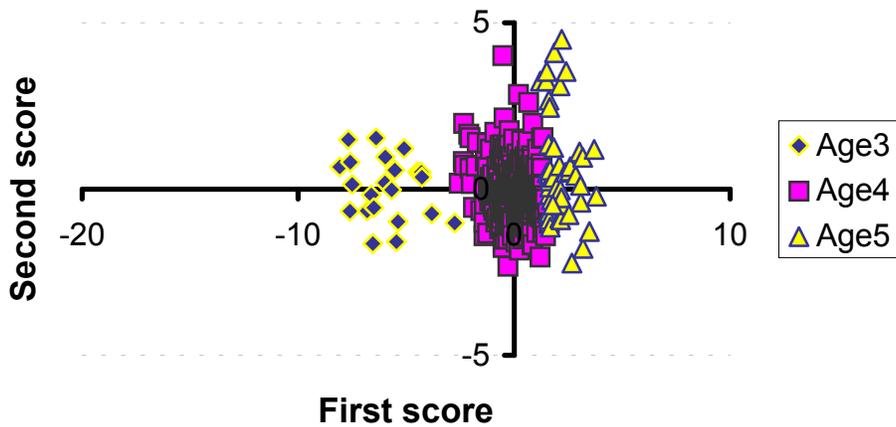


Figure 3. Wild-origin canonical scores from a discriminant function analysis using log (POHP) and log (Body weight) as discriminators. Classification rates are given in Table 4.

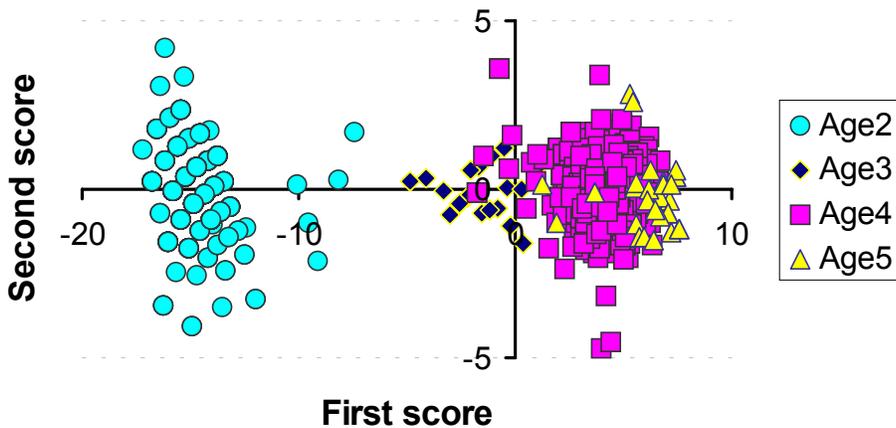


Figure 4. Hatchery-origin canonical scores from a discriminant function analysis using log (POHP) and log (Body weight) as discriminators. Classification rates are given in Table 5.

Table 5. Jackknifed classification matrix from a linear discriminant function analysis estimating the ageing accuracy of hatchery origin spring chinook based on RAMF log transformed POHP length and body weight in 2002. “Age classification” cells show the number of fish of known age that were classified as age-2, -3, -4 or -5. The percentage classified into each category is in parentheses. Overall mean accuracy is the mean of the “Percent correctly classified” values.

| Known age             | Age classification – N (%) |             |              |             | Percent correctly classified |
|-----------------------|----------------------------|-------------|--------------|-------------|------------------------------|
|                       | Age 2                      | Age 3       | Age 4        | Age 5       |                              |
| Age 2                 | 474 (99.8.0%)              | 1 ( 0.2%)   | 0 ( 0.0%)    | 0 ( 0.0%)   | 99.8.0%                      |
| Age 3                 | 0 ( 0.0%)                  | 37 (100.0%) | 0 ( 0.0%)    | 0 ( 0.0%)   | 100.0%                       |
| Age 4                 | 0 ( 0.0%)                  | 15 ( 0.6%)  | 2277 (86.5%) | 339 (12.9%) | 86.5%                        |
| Age 5                 | 0 ( 0.0%)                  | 2 ( 2.8%)   | 7 ( 9.9%)    | 62 (87.3%)  | 87.3%                        |
| Overall mean accuracy |                            |             |              |             | 93.4%                        |

## Upper Yakima River Hatchery Origin

Age composition of hatchery origin fish was estimated from the scale samples collected at RAMF. The estimated proportion of hatchery origin jacks was 2% based on visual length classifications at RAMF and age-4 and -5's made up the remaining 83 and 15% of the returns, respectively (Table 3). The proportion of each sex in 100 age-4 adult hatchery fish held at CESRF were used to partition the RAMF age-4 class by sex (Table 6).

## American River and Naches

Based on scale sampled carcass recoveries, age composition from the American River was 1, 55 and 44% age-3, -4 and -5, respectively, while Naches system fish were 1, 68 and 31% age-3, -4 and -5, respectively (Table 6). The American River population

| Population            | Sex    | Age | N  | Percent by sex | Overall percent |
|-----------------------|--------|-----|----|----------------|-----------------|
| American River        | Male   | 3   | 1  | 1.7            | 0.6             |
|                       |        | 4   | 32 | 54.2           | 18.9            |
|                       |        | 5   | 26 | 44.1           | 15.4            |
|                       | Female | 3   | 0  | 0              | 0               |
|                       |        | 4   | 62 | 56.4           | 36.7            |
|                       |        | 5   | 48 | 43.6           | 28.4            |
| Naches system         | Male   | 3   | 1  | 2.1            | 0.7             |
|                       |        | 4   | 37 | 78.7           | 25.5            |
|                       |        | 5   | 9  | 19.1           | 6.2             |
|                       | Female | 3   | 0  | 0              | 0               |
|                       |        | 4   | 62 | 67.2           | 42.8            |
|                       |        | 5   | 36 | 32.8           | 24.8            |
| Upper Yakima Wild     | Male   | 3   | 1  | 11.1           | 2.6             |
|                       |        | 4   | 8  | 80.9           | 20.5            |
|                       |        | 5   | 0  | 0              | 0               |
|                       | Female | 3   | 0  | 0.0            | 0.0             |
|                       |        | 4   | 29 | 96.7           | 74.4            |
|                       |        | 5   | 1  | 3.3            | 2.6             |
| Upper Yakima Hatchery | Male   | 3   | 0  | 0              | 0               |
|                       |        | 4   | 23 | 76.5           | 21.3            |
|                       |        | 5   | 0  | 0.0            | 0.0             |
|                       | Female | 3   | 0  | 0              | 0               |
|                       |        | 4   | 85 | 99.1           | 78.7            |
|                       |        | 5   | 0  | 0              | 0               |

had more age-5 fish than the Naches, as noted in earlier analyses (Major and Mighell 1969; Fast et al. 1991; Knudsen 1991), and the age compositions (excluding jacks) were significantly different in 2002 ( $X^2=6.56$  with Yates correction;  $df=1$ ;  $p=0.010$ ),

## Sexual Dimorphism and Development of Secondary Sex Characteristics

### Sexual Dimorphism

Mean POHP lengths of American, Naches and upper Yakima populations by sex and age are given in Table 7. We compared POHP length and Body Weight of upper Yakima River wild and Hatchery origin age-4 and -5 fish using ANOVA. Sex effects were estimated for each age class. Age-4 and -5's were analyzed separately because previous results showed that there were significant Sex effects for age-5 fish only (Knudsen et al. 2002) and the 2002 returns appeared to follow the same trend (Fig. 5). Results of the 1-way ANOVA of POHP length and Body weight are given in Tables 8 and 9, respectively. Since there were no hatchery age-5 male carcass recovery samples, we could not test for Sex effects in the age-5 hatchery group. As in 2001, we found no

| Table 7. Mean POHP length of American and Naches (carcass recoveries) and upper Yakima wild and hatchery origin (CESRF samples) spring chinook. |        |     |           |     |     |   |
|---|--------|-----|-----------|-----|-----|---|
| Population  | Sex    | Age | POHP (cm) | sd  | N   |   |
| American River  | Male   | 3   | 40.0      |     | 1   |   |
|   |        | 4   | 63.0      | 6.9 | 31  |   |
|   |        | 5   | 77.3      | 5.2 | 26  |   |
|   | Female | 3   |           |     |     | 0 |
|   |        | 4   | 64.4      | 3.9 | 62  |   |
|   |        | 5   | 74.7      | 5.4 | 48  |   |
| Naches system   | Male   | 3   | 40.0      |     | 1   |   |
|   |        | 4   | 63.6      | 5.0 | 37  |   |
|   |        | 5   | 77.3      | 6.3 | 9   |   |
|   | Female | 3   |           |     |     | 0 |
|   |        | 4   | 62.4      | 4.1 | 62  |   |
|   |        | 5   | 71.8      | 2.9 | 36  |   |
| Upper Yakima wild   | Male   | 3   | 42.0      | 3.9 | 26  |   |
|   |        | 4   | 61.6      | 5.1 | 189 |   |
|   |        | 5   | 76.7      | 5.3 | 40  |   |
|   | Female | 3   | 36.6      |     | 1   |   |
|   |        | 4   | 61.8      | 3.9 | 386 |   |
|   |        | 5   | 73.1      | 4.7 | 95  |   |
| Upper Yakima Hatchery   | Male   | 3   | 40.2      | 3.3 | 2   |   |
|   |        | 4   | 60.0      | 4.5 | 49  |   |
|   |        | 5   |           |     | 0   |   |
|   | Female | 3   | 41.0      |     | 1   |   |
|   |        | 4   | 59.1      | 3.8 | 148 |   |
|   |        | 5   | 66.2      | 7.1 | 2   |   |

significant Sex effects in age-4 hatchery or wild fish. Mean POHP lengths differed by <0.4 cm and body weights by <0.2 kg. However, there was a significant difference between wild origin age-5's ( $p \leq 0.05$ ), with males being 3.5 cm longer and 2.0 kg heavier on average than females.

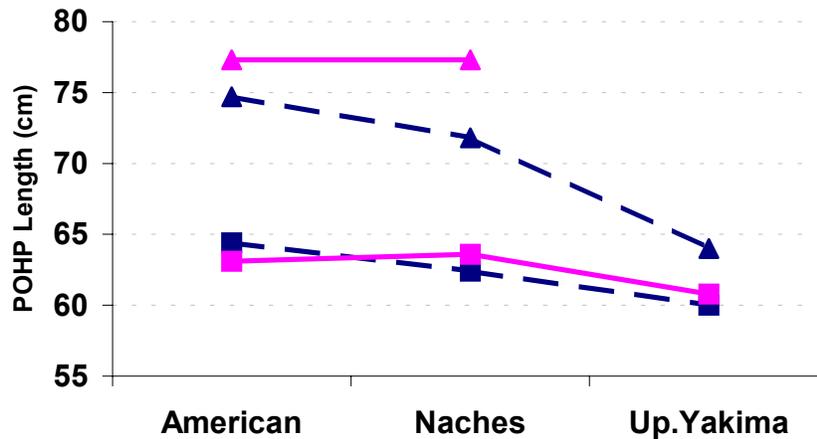


Figure 5. Mean POHP length of age-4 (squares) and age-5 (triangles) American River, Naches system, and Yakima River wild populations by male (solid lines) and female (broken lines) as estimated from YN carcass recoveries in 2002.

| Table 8. One-way ANOVA results for POHP length estimating Sex (male and female) effects from Wild origin age-4, wild origin age-5 and hatchery origin age-4 recoveries in 2002. |            |        |                 |     |             |         |         |
|---|------------|--------|-----------------|-----|-------------|---------|---------|
| Population  | Type/Age   | Source | Sums-of-Squares | df  | Mean-Square | F-ratio | P-value |
| Upper Yakima River  | Wild 4     | SEX    | 21.3            | 1   | 21.3        | 1.6     | 0.200   |
|   |            | Error  | 5337.4          | 412 | 13.0        |         |         |
|   | Wild 5     | SEX    | 68.6            | 1   | 68.6        | 4.2     | 0.053   |
|   |            | Error  | 341.5           | 21  | 16.3        |         |         |
|   | Hatchery 4 | SEX    | 3.7             | 1   | 3.7         | 0.2     | 0.635   |
|   |            | Error  | 1696.2          | 104 | 16.3        |         |         |
| American River  | Age 4      | SEX    | 36.2            | 1   | 36.2        | 1.4     | 0.235   |
|   |            | Error  | 2332.7          | 92  | 25.4        |         |         |
|   | Age 5      | SEX    | 108.8           | 1   | 108.8       | 3.8     | 0.054   |
|   |            | Error  | 2040.6          | 72  | 28.3        |         |         |
| Naches  | Age 4      | SEX    | 32.6            | 1   | 32.6        | 1.6     | 0.203   |
|   |            | Error  | 1927.9          | 97  | 19.9        |         |         |
|   | Age 5      | SEX    | 224.5           | 1   | 224.5       | 15.8    | <0.001  |
|   |            | Error  | 610.8           | 43  | 14.2        |         |         |

Table 9. One-way ANOVA results for Body weight estimating Sex (male and female) effects from Wild origin age-4, wild origin age-5 and hatchery origin age-4 recoveries in 2002.

| Origin/age | Source | Sums-of-Squares | df  | Mean-Square | F-ratio | P     |
|------------|--------|-----------------|-----|-------------|---------|-------|
| Wild 4     | SEX    | 0.2             | 1   | 0.2         | 0.3     | 0.567 |
|            | Error  | 265.4           | 412 | 0.6         |         |       |
| Wild 5     | SEX    | 21.6            | 1   | 21.6        | 5.7     | 0.027 |
|            | Error  | 79.9            | 21  | 3.8         |         |       |
| Hatchery 4 | SEX    | 0.8             | 1   | 0.8         | 1.3     | 0.265 |
|            | Error  | 70.2            | 104 | 0.7         |         |       |

Male and female mean POHP lengths of Naches and American River populations are given in Table 7 and Fig. 5. We used a 1-way ANOVA to test for Sex effects (Male vs Female) in POHP length distributions (Table 8). There was no significant Sex effect in the American and Naches age-4's ( $p \geq 0.20$ ). In contrast, the American and Naches age-5's did exhibit significant sexual dimorphism ( $p \leq 0.05$ ), with male POHP length greater than female length by  $\geq 2.6$  cm; similar to what was observed in the upper Yakima River.

Table 10. Mean differences between paired samples of fork length (FL), post-orbital hypural plate length (POHP) and body weight (BW) measured on the same fish at RAMF and then subsequently at CESRF. Differences were calculated as RAMF value minus CESRF value. Differences were compared to a null hypothesis of 0 difference (paired sample t-test;  $\alpha=0.05$ ; 2-tailed).

| Origin | Age | Sex    | N   | FL (cm) | POHP (cm) | BW (kg) |
|--------|-----|--------|-----|---------|-----------|---------|
|        | 3   | Male   | 16  | -1.28** | -0.01     | 0.37**  |
|        |     | Female | 0   |         |           |         |
|        | 4   | Male   | 138 | -3.91** | <-0.01    | 0.82**  |
|        |     | Female | 295 | -2.94** | 0.01      | 0.60**  |
|        | 5   | Male   | 5   | -5.20** | 0.72*     | 1.12**  |
|        |     | Female | 12  | -2.98** | 0.33      | 0.81**  |

\*\* indicates  $p \leq 0.01$ .

\* indicates  $p \leq 0.05$

### Development of Secondary Sex Characteristics

The difference (RAMF value-CESRF value) between paired lengths and weights from the same fish sampled at RAMF and then at CESRF were analyzed to determine the changes in traits over time (Table 10). Fork length and Body weight showed significant changes in every paired sample (all ages and sexes  $p < 0.01$ ), while POHP lengths were significant only in age-5 males ( $p < 0.05$ ). Thus, POHP lengths taken at CESRF or at RAMF should be equally representative of a fish's length. Fork lengths increased due primarily to the development of the kype, a secondary sexual characteristic. Male FL increased by 5 to 6% and female FL increased by 4% on average during the 1-5 months

fish were held at CESRF. Body weight consistently decreased over time. Male and female weight decreased by 18 to 22% and 15 to 16%, respectively.

### Size-at-age

#### Hatchery and Wild Origin Returns

We made hatchery/wild and 2001/2002 comparisons across age-3 and -4's in a 3-way ANOVA testing for Year, Origin, and Age effects. In both 2001 and 2002, wild fish were larger than hatchery fish (Tables 11 and 12; Origin effects  $p < 0.01$ ). Age-3 wild fish were 3 cm longer and 0.2 kg heavier than age-3 hatchery fish, while age-4 wild fish were 1.8 cm longer and 0.3 kg heavier than hatchery fish. There was also a significant difference in size between fish returning in 2001 and 2002 (Year effect  $p \leq 0.04$ ). Returns in 2001 were slightly less than 1 cm longer and 0.2 kg heavier than returns in 2002. There were only 2 age-5 hatchery females identified, so no estimate of Origin and Sex effects could be made for age-5's. However, if the sexes are pooled (likely introducing some error due to significant Sex effects in age-5's) the mean POHP lengths for age-5 hatchery ( $n=34$ ) and wild ( $n=31$ ) fish are 67.0 and 70.1 cm, respectively, indicating that the size-at-age difference extends into the age-5 class. Returns in 2003 should be heavily weighted toward age-5 returns due to the strength of the 1998 brood relative to the weak 1999 brood, and we anticipate having a robust sample from the age-5 class in 2003.

Table 11. Three-way ANOVA results for POHP length estimating Origin (upper Yakima wild and hatchery), Age (3 vs 4), and Year (2001 vs 2002) effects.

| Source          | Sums-of-Squares | df   | Mean-Square | F-ratio | P      |
|-----------------|-----------------|------|-------------|---------|--------|
| Origin          | 797.3           | 1    | 797.3       | 52.1    | <0.001 |
| Age             | 51993.7         | 1    | 51993.7     | 3400.1  | <0.001 |
| Year            | 65.4            | 1    | 65.4        | 4.3     | 0.039  |
| Origin*Age      | 40.5            | 1    | 40.5        | 2.7     | 0.104  |
| Origin*Year     | 2.2             | 1    | 2.2         | 0.1     | 0.706  |
| Age*Year        | 20.8            | 1    | 20.8        | 1.4     | 0.243  |
| Origin*Age*Year | 0.2             | 1    | 0.2         | <0.1    | 0.913  |
| Error           | 74012.2         | 4840 | 15.3        |         |        |

Table 12. Three-way ANOVA results for Body weight estimating Origin (upper Yakima wild and hatchery), Age (3 vs 4), and Year (2001 vs 2002) effects.

| Source          | Sums-of-Squares | df   | Mean-Square | F-ratio | P      |
|-----------------|-----------------|------|-------------|---------|--------|
| Origin          | 13.7            | 1    | 13.7        | 21.7    | 0.009  |
| Age             | 1189.8          | 1    | 1189.8      | 1888.8  | <0.001 |
| Year            | 4.3             | 1    | 4.3         | 6.8     | <0.001 |
| Origin*Age      | <0.1            | 1    | <0.1        | <0.1    | 0.969  |
| Origin*Year     | 0.2             | 1    | 0.2         | 0.3     | 0.590  |
| Age*Year        | 0.1             | 1    | 0.1         | 0.2     | 0.646  |
| Origin*Age*Year | <0.1            | 1    | <0.1        | <0.1    | 0.879  |
| Error           | 3049.0          | 4840 | 0.6         |         |        |

## OCT vs SNT

There was only 0.2 cm and 0.02 kg difference between the OCT and SNT age-4 groups in 2002 and, in general, there was very little difference in size-at-age between the two groups. Means for all age class and treatment groups are given in Table 13. There was no significant Treatment effect (OCT vs. SNT) found for POHP length ( $p=0.15$ ) or body weight ( $p=0.68$ ) and Age\*Treatment interaction effects were not significant ( $p \geq 0.23$ ; Tables 14 and 15).

| Age | Treatment | Body weight (kg) | POHP length (cm) | N   |
|-----|-----------|------------------|------------------|-----|
| 2   | OCT       | 0.08 (0.01)      | 15.2 (1.3)       | 323 |
|     | SNT       | 0.08 (0.04)      | 15.1 (0.9)       | 132 |
| 3   | OCT       | 1.21 (0.52)      | 39.3 (4.1)       | 12  |
|     | SNT       | 1.11 (0.39)      | 37.7 (4.4)       | 12  |
| 4   | OCT       | 4.10 (0.80)      | 59.1 (3.9)       | 466 |
|     | SNT       | 4.12 (0.77)      | 59.3 (3.6)       | 463 |
| 5   | OCT       | 5.66 (1.71)      | 66.9 (8.0)       | 7   |
|     | SNT       | 6.02 (1.14)      | 68.2 (3.0)       | 5   |

| Source    | Sums-of-Squares | df   | Mean-Square | F-ratio | P      |
|-----------|-----------------|------|-------------|---------|--------|
| TREATMENT | <0.1            | 1    | <0.1        | 0.2     | 0.683  |
| AGE       | 4245.1          | 3    | 1415.0      | 27062.7 | <0.001 |
| TRT*AGE   | 0.1             | 3    | <0.1        | 0.6     | 0.608  |
| Error     | 73.8            | 1411 | 0.1         |         |        |

| Source    | Sums-of-Squares | df   | Mean-Square | F-ratio  | P      |
|-----------|-----------------|------|-------------|----------|--------|
| TREATMENT | 0.01            | 1    | 0.01        | 2.07     | 0.150  |
| AGE       | 499.21          | 3    | 166.40      | 33748.63 | <0.001 |
| TRT*AGE   | 0.02            | 3    | 0.01        | 1.42     | 0.234  |
| Error     | 6.96            | 1411 | 0.01        |          |        |

## American River and Naches system

American River and Naches mean POHP lengths by sex and age are shown in Figure 4. There were no significant differences between age-4 males or females in any of the Yakima River populations (Table 16). Age-4 fish from the American River (mean=64.0 cm) were larger than Naches fish (mean=62.9 cm), while upper Yakima fish (mean=62.1 cm) were smallest. Upper Yakima fish were significantly smaller than American fish ( $p=0.05$ ; Tukey multiple-comparisons test). Age-5 females followed this

same general trend with American the largest (mean=74.7 cm), followed by Naches (mean =71.8 cm), and upper Yakima (mean=69.2). American River age-5 males (mean= 77.3 cm) were the same length and Naches males (mean= 77.3 cm).

| Table 16. Two-way ANOVA results comparing POHP lengths of age-4 American, Naches and upper Yakima populations by sex estimating Population (Amer./Naches/UpYak.) and Sex (Male vs Female) effects from carcass recoveries. |                 |     |             |         |       |
|--|-----------------|-----|-------------|---------|-------|
| Source   | Sums-of-Squares | df  | Mean-Square | F-ratio | P     |
| Population   | 217.4           | 2   | 108.7       | 5.0     | 0.007 |
| Sex  | 1.1             | 1   | 1.1         | 0.1     | 0.819 |
| Pop*Sex  | 76.6            | 2   | 38.3        | 1.8     | 0.172 |
| Error  | 4811.7          | 223 | 21.6        |         |       |

### Run/Spawn Timing

#### RAMF Passage Timing

Mean and median passage timing of hatchery (n=6,385) and wild (n=631) fish (all fish greater than 35 cm fork length, whether aged or not) at RAMF differed by 4 and 7 days, respectively, with wild fish passing earlier than hatchery fish (Figs. 2 and 6). The two group’s passage timing distributions were significantly different in a K-S test (p<0.001).

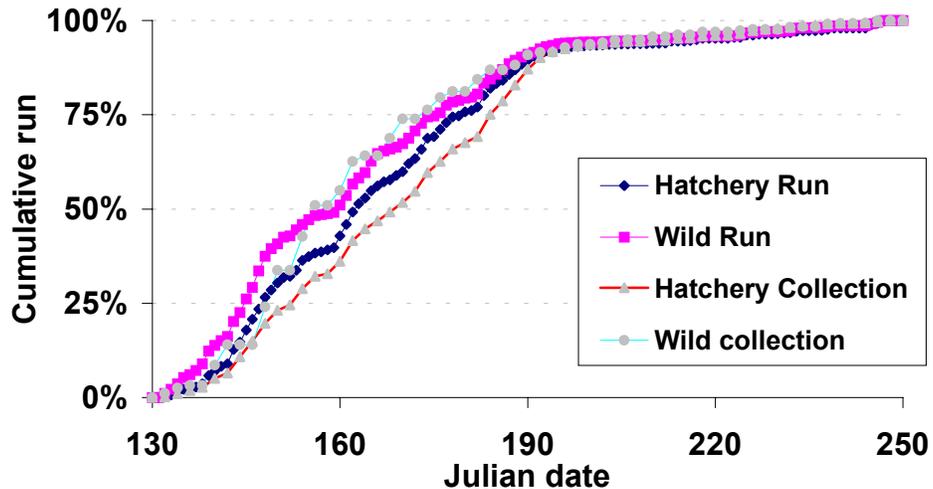


Figure 6. Cumulative passage timing at RAMF for the hatchery (♦) and wild (■) origin spring chinook run and the hatchery (▲) and wild (●) collections taken to CESRF in 2002.

When passage timing is broken down into age classes (sexes pooled) there were distinct trends observed. Age-5’s passed earliest on average (Julian date=157.6),

followed by age-4's (Julian date=163.5) and age-3's (Julian date=182.0). In a 2-way ANOVA looking at Origin (Hatchery vs Wild) and Age (3, 4, and 5) effects (Table 17), both Origin ( $p=0.05$ ) and Age ( $p<0.001$ ) were significant, while the interaction term was not ( $p=0.264$ ).

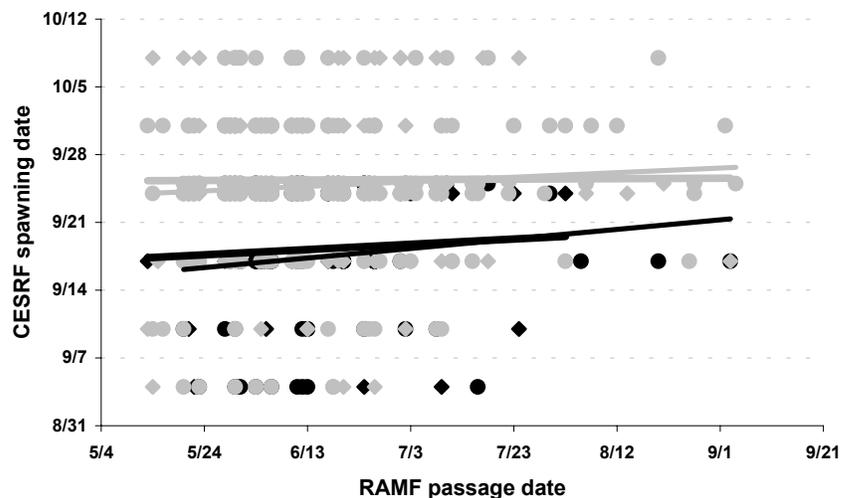
| Source     | Sums-of-Squares | df   | Mean-Square | F-ratio | P      |
|------------|-----------------|------|-------------|---------|--------|
| Origin     | 1668.7          | 1    | 1668.7      | 3.9     | 0.048  |
| Age        | 24389.7         | 2    | 12194.9     | 28.7    | <0.001 |
| Origin*Age | 1130.4          | 2    | 565.2       | 1.3     | 0.264  |
| Error      | 927778.0        | 2186 | 424.4       |         |        |

### OCT vs SNT

We compared OCT and SNT treatment groups' passage timing at RAMF for age-3 and -4 fish using K-W ANOVA and found no significant treatment effect on passage timing ( $p>0.232$ ) within any age class. OCT and SNT medians and means within age classes differed by no more than 2 days.

### Relationship of CESRF Spawning Date to RAMF Passage Timing

Neither wild nor hatchery origin males or females demonstrated a significant linear relationship between passage date at RAMF and date of spawning at CESRF in 2002 ( $p\geq 0.25$ ). Results from 2001 were essentially the same. The lower (earlier) position of the hatchery regression trend lines in Figure 7 highlights the earlier spawn timing of both male and female hatchery fish at CESRF.



**Figure 7. Linear relationship between passage date at Roza Adult Monitoring Facility (RAMF) and date fish were spawned at CESRF for hatchery (black) and wild (gray) origin females (circles) and males (diamonds). None of the relationships was statistically significant ( $p\geq 0.25$  and  $R^2<0.02$ ).**

## Spawn Timing

Mean spawn timing of both upper Yakima River hatchery and wild fish based on in-river carcass recoveries was Sept. 25 in 2002. The median date for both populations was September 26. This compares to means of September 25 and 26 in 2001. Mean and median spawn timing based on carcass recoveries were August 17 and 20, respectively, for the American River (n=181) and September 14 and 19, respectively, for the Naches (n=154) population. There were significant differences in spawn timing between the three populations in a K-W test ( $p < 0.001$ ).

## Carcass Recovery Bias

### Relationship between RAMF and Carcass recoveries

The proportions of hatchery and wild origin jacks passed upstream at RAMF were 9 and 2%, respectively, in 2002. However, hatchery and wild origin jacks made up only 2 and 0% of the carcasses recovered. Only one age-3 and one age-5 fish were recovered in the YN upper Yakima River spawning ground samples, making any statistical comparisons by age class uninformative.

The F:M ratio of wild and hatchery origin fish (including jacks) was 1.89 in the CESRF sample (n=509) and 4.75 in the carcass recover sample (n=184). As in 2001, females represented a significantly larger proportion of the carcass sample ( $X^2=18.19$  with Yates correction;  $p < 0.001$ ), demonstrating that female carcasses were recovered at higher rates than male carcasses.

## Discussion

### Sex Ratio

There was no significant difference between hatchery and wild sex ratios in 2002 between fish sampled either at CESRF or as in-river carcass recoveries. However, as in 2001 significant differences were found between the sex ratios of the American, Naches and upper Yakima populations. This may be because fewer males residualize as nonanadromous precocial males in the American River and Naches populations. Spring chinook precocialism is a plastic life history strategy adopted by males (Pearsons et al. 2003) that is strongly mediated by growth rate and environmental conditions (Larsen et al., in review). The growth potential in the upper Yakima is greater than in the higher elevation, cooler, less productive Naches and American rivers. In addition, the steeper gradient of the Naches and American rivers is a more formidable selection force against small males successfully migrating back upstream to the spawning grounds. Thus, the upper Yakima is more conducive to precocious male development and success. Since precocials are virtually never recovered during spawning ground carcass surveys, they “drop out” of our carcasses monitoring efforts and are very difficult to quantify directly. Ultimately, they reduce the proportion of returning anadromous males in the cohort. Adult sex ratios near 1:1, as in the American population, will result in greater average

adult male competition than in populations with a F:M ratio of 3 or 4, such as the upper Yakima River. This is because there are more anadromous males per female in the American River, increasing the likelihood of competition between males for this relatively scarce resource. It is worth noting that both upper Yakima hatchery and wild populations had comparable F:M ratios in both 2001 and 2002, indicating that the total proportion of wild and hatchery males “dropping out” due to precocialism may be quite similar. This is at odds with the conclusions of Larsen et al. (in review) who found that the CESRF hatchery produced a significantly higher proportion of precocious males than the naturally spawning population.

### **Age Composition**

Because only 2 age-5 hatchery fish were collected at RAMF as broodstock in 2002, statistical comparisons between hatchery and wild upper Yakima populations were not informative. However, there was little difference in age compositions in 2002 with age-4 fish dominating in both populations. Age compositions were not different within samples either collected at RAMF or collected as in-river carcasses. However, as with sex ratios above, the RAMF and in-river carcass samples were significantly different. Relative to the RAMF collection, carcass recoveries overestimated the proportion of older, larger fish. This result is also in agreement with the results of Peterson (1954), Clutter and Whitesel (1956), Ward (1959), Boechler and Jacobs (1987), Knudsen (1992), Knudsen et al. (2002) and Zhou (2002). Larger fish are larger targets and thus easier to visually locate and recover. In addition, larger fish tend to tangle and catch in woody debris more easily, are more difficult for flow to displace downstream (particularly during low flows), and harder for predators to drag up out of the streambed. In general, age composition of spawning grounds samples should not be assumed to represent the spawning population without verification.

### **Sexual Dimorphism and Development of Secondary Sex Characteristics**

American, Naches and upper Yakima River hatchery and wild origin age-4 fish displayed no significant sexual dimorphism in body size (POHP length or body weight). Knudsen (1991) and Knudsen et al. (2002) also found that mean POHP lengths of age-4 upper Yakima River male and female carcass recoveries were not significantly different. This is in contrast to the 2001 American River age-4's that did exhibit significant sexual dimorphism.

As spring chinook complete the final stages of the maturation process, they convert calcium stores, lipids and muscle tissue into gametes and secondary sexual characteristics (e.g. large canine teeth, toughened epidermis and kype), while depleting fat and lipid stores to sustain themselves (Hendry et al. 2000). This would explain the reduction in body weight over time. However, a small portion of the decrease in body weight we observed was also due to the “bleeding” process that occurs at CESRF during artificial spawning. Just after fish are sacrificed, but prior to being weighed, their gill arches are severed and the fish are bled. We do not have an estimate of what proportion

of total body weight blood loss represents at this time. Therefore, our weight loss estimates are over-estimated to some degree.

POHP length, whether taken at RAMF or CESRF 1-5 months later, were equally representative of a fish's length. Thus, POHP lengths from spawners and maturing fish at RAMF can be used together in analyses of size without concern for the temporal differences confounding results. However, body weight and FL were significantly affected by the time lag in sampling due to secondary sexual character development and depletion of energy stores, and care should be taken to analyze these measurements only when they are collected from fish in the same state of maturity.

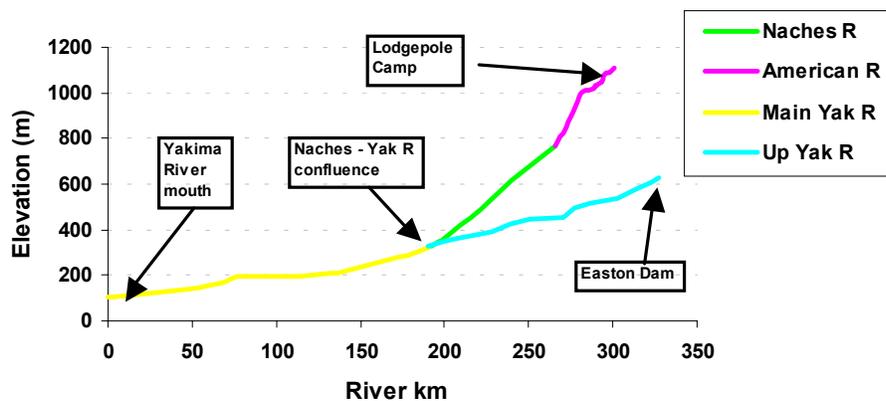
### **Size-at-Age**

Age-4 hatchery fish were smaller than wild fish returning in 2002: approximately 2 cm POHP length and 0.3 kg body weight. This trend was also true for age-3 and age-5 fish. This same difference was observed in 2001 returns. The difference in POHP length between first generation hatchery and wild origin fish is similar to results reported in two other hatchery supplementation projects: Tucannon River spring chinook and Cedar River sockeye. Tucannon River hatchery origin returns were significantly smaller-at-age during the initial years of operation (Bumgarner et al. 1994). Fresh et al. (in prep.) found that first generation Cedar River hatchery sockeye returns were as much as 5 cm smaller in POHP length than wild conspecifics and in the majority of their comparisons hatchery fish were significantly smaller than wild returns. In addition, Unwin and Glova (1997) found that New Zealand hatchery reared male chinook returned 0.6 cm smaller than wild males.

The development of differences in traits between hatchery and wild origin fish derived from the same native stock may have a significant genetic component due to unintentional directional selection (domestication) or relaxation of natural selection pressures in the hatchery (Hard 1995; Lynch and O'Hely 2001). They may also be caused by phenotypic plasticity due to environmental variation (Stearns 1989) or be a result of a complex combination of both environmental and genetic factors (Riddle 1986; Taylor 1991). In both the Tucannon and New Zealand studies cited above, hatchery fish were much larger at release relative to their wild counterparts and this hatchery environmental factor, not selection on a heritable trait, was the primary cause of the observed difference in size at return. However, Cedar River sockeye fry are released into the river as unfed fry at the same size and time as wild fry and in CESRF spring chinook smolts are only slightly larger than wild smolts migrating contemporaneously. Thus, it does not appear that size-at-release is likely the cause of phenotypic differences we observed in adult size.

One environmentally driven difference between wild and hatchery upper Yakima River spring chinook that could potentially contribute to size-at-age differences is differential timing of the wild and hatchery smolt outmigrations and entrance into the Columbia River estuary. Because size differences were consistently observed in age-3 as well as, age-4 and -5's, the causal mechanism(s) must occur prior to age-3 fish returning.

That is, between release and the first 18 months of post-release ocean rearing. Bilton (1980) found that a one month difference in time-of-release could cause >0.3 kg difference in average adult coho return body weights. There is a large amount of data from PIT tag monitoring of CESRF juvenile movement through the Columbia River that, once analyzed, may help explain differences between hatchery and wild smolt outmigration behavior and timing. There may be a critical temporal window when growth of smolts entering the Columbia River estuary is maximized due to high food availability and/or lower competition. It could be that smolts entering the estuary first have the longest exposure to the most productive estuarine rearing area and/or transition into the ocean earlier, resulting in an initial growth advantage that later arriving smolts are never able to overcome before reaching maturity.



**Figure 8. Elevation and river distances to the major spawning areas of the American River, Naches, and upper Yakima River spring chinook characterizing their adult return migration. No tributaries are not shown.**

Age-4 American River and Naches populations were significantly larger in POHP length than either upper Yakima River hatchery or wild populations. This was also true of age-5 fish in 2002. The selection pressures experienced by the American and, to a lesser degree, the Naches populations have caused local adaptations resulting in significantly larger size-at-age and older mean age compared to the wild upper Yakima River population. Total migration distance traveled within the Yakima River basin by each population to their respective spawning areas is not greatly different: upper Yakima fish travel up to 327 river kilometers (rkm) to Easton, American River up to 279 rkm, and Naches up to 259 rkm (Fig. 8). However, elevation of the respective spawning grounds is a significant selection pressure that differs between populations. American River fish spawn at the highest elevations, followed by the Naches and finally the upper Yakima (Fig. 8). Thus, the American River and Naches populations negotiate a much steeper gradient than upper Yakima fish. The elevation and distance traveled by the Naches population lies intermediate between the American and upper Yakima rivers, and the size-at-age and mean age at return of Naches fish also falls intermediate between these two populations. There are significant trade offs that must be made between energy budgeted toward migration needs and other “bins” such as gametes (total mass, egg

number, egg size), body size, secondary sexual characteristics, competition and nest guarding (Kinnison et al 2001). American River and Naches fish must budget a greater proportion of their total energy budget into migration related bins because of their steeper migration route. Life history theory suggests that within each population the allocation between all bins should coevolve so that lifetime reproductive success will be maximized (Pianka 1976; Roff 1988). Larger size and greater muscle mass should increase the likelihood of successfully completing a steeper gradient migration and this selection pressure is one reason American River fish are significantly larger at age and older at return. A steeper gradient also increases the likelihood of gravel scouring, thus selecting for larger females that can deposit eggs deeper in the substrate below the level of vulnerability (van den Berghe and Gross 1989; Montgomery et al. 1996).

### **Run/Spawn Timing**

We observed significant differences between hatchery and wild fish passing RAMF in 2002. Wild fish passed earlier than hatchery fish by 5 days on average. Hatchery and Wild carcasses also had the same mean dates of recovery on the spawning grounds. In 2001 there were no significant differences between hatchery and wild fish in terms of either run timing or spawn timing as represented by passage date at RAMF, redd observations over time, or in-river carcass recoveries. There were however, large differences between upper Yakima River, American River, and Naches populations in temporal distribution of carcass recoveries. This has been noted by other researchers, as well (Major and Meghell 1969; Fast et al. 1991; Knudsen et al. 2002). The American River is the earliest spawning group, followed by the Naches and finally the upper Yakima River. Fry emergence is often synchronized across populations within a river system occurring during the optimum spring period maximizing survival (Brannon 1987). American and upper Yakima River fry emergence timing does appear to be synchronized (Fast et al. 1991). The populations with the coldest water temperatures spawn first so that the eggs' total temperature unit accumulations, which determine fry emergence timing, will be equivalent across populations at emergence. Thus, temporal differences in spawning are driven by water temperatures during egg incubation, which are coldest in highest elevation American River, followed by the Naches, and warmest in the lower elevation upper Yakima. In addition, since upper Yakima River fish spawn over a month later on average than American River fish, they must have the energy reserves to maintain themselves over an additional month of holding, when mean water temperatures are warmer and daily metabolic costs are higher. Because of this, we hypothesize that upper Yakima fish should invest more into somatic growth that can be quickly and efficiently metabolized (i.e. visceral fat stores) and devote relatively less growth into muscle mass, which is less efficiently converted back to energy, than American River fish. This would also tend to produce larger fish at age in the American River population.

### **Carcass Recovery Bias**

We found that in-river carcass samples differed significantly from expectations based on RAMF trap samples because females and larger fish were recovered at higher rates than males and smaller fish. These results are consistent with the findings of

Peterson (1954), Clutter and Whitesel (1956), Ward (1959), Boechler and Jacobs (1987), Knudsen (1992), Knudsen et al. (2002), and Zhou (2002). The difference in recovery rates may be due to behavioral differences between males and females, the visibility and “catchability” of larger versus smaller targets, the ease with which smaller carcasses are removed by terrestrial predators, and displaced downstream out of the search area by flow. The magnitude of the bias is likely affected by a stream’s hydrological characteristics. In addition, in years with high flows and high turbidity, carcass recovery bias will likely be different than in low flow, high visibility years. Male spring chinook salmon tend to remain active on the spawning grounds over a longer period than females (Schroder et al. 2002). Spawning survey effort in the Yakima River historically drops off after new redd construction ceases. However, we may be able to increase the number of male carcass recoveries and reduce sex bias by continuing surveys past the period of new redd construction until all males have died.

## Conclusions

The observed differences in size-at-age after only a single generation of domestication over two successive return years are both statistically and biologically significant. Irrespective of the underlying causes, displacement of POHP length from the locally adapted optimum will reduce the productivity and fitness of naturally spawning hatchery fish through counter selection pressure against the smallest hatchery fish. In addition, other unmonitored traits correlated with body size have also been shifted away from their locally adapted optima, and counter selection in the wild acting on these traits will result in additional reductions in fitness and productivity driving the trait distributions back toward their locally adapted optimum over time. The magnitude of the one-generation response in POHP length represents a selection response of approximately  $0.5 \text{ standard deviation} \cdot \text{generation}^{-1}$  or 0.5 haldane (Haldane 1949) in age-4 fish. Size-at-age is a heritable trait influenced by both natural and sexual selection pressures (Schroder 1981; Blair et al. 1993; Quinn and Foote 1994; Fleming and Petersson 2001; Hendry 2001), and responds to artificial selection (Gjerde and Gjerdem 1984; Su et al. 2002), so the potential for a genetic response exists. However, size-at-age is also subject to environmentally driven phenotypic plasticity (Riddell 1986; Hard 1995). Identifying the mechanism(s) or cause(s) of the reduction in size-at-age is critical to understanding supplementation’s impacts on natural productivity. A study to monitor and estimate the affects of domestication on supplementation in the YKFP was begun in 2002 (Busack et al. 2002). This effort will be crucial to helping us understand and identify the genetic component to the observed differences in traits, such as size-at-age.

We documented significant variation in traits between the three Yakima River basin wild spring chinook populations, including size-at-age, age composition, sex ratios, sexual dimorphism, and spawn timing. These differences appear to reflect local adaptations by each population to their unique set of selection pressures.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

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## **Chapter 2**

# **Monitoring Phenotypic and Demographic Traits of upper Yakima River Hatchery and Wild Spring Chinook: Gametic and Juvenile Traits**

Prepared by:

Curtis M. Knudsen<sup>1</sup>, Steve L. Schroder<sup>2</sup>, Todd N. Pearsons<sup>3</sup>, Jason A. Rau<sup>4</sup>,

Anthony L. Fritts<sup>3</sup>, and Charles R. Strom<sup>4</sup>

<sup>1</sup> Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

<sup>2</sup> Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501-1091

<sup>3</sup> Washington Department of Fish and Wildlife, 201 N. Pearl Street, Ellensburg, WA 98926

<sup>4</sup> Yakama Nation, Cle Elum Research and Supplementation Facility, Cle Elum, WA 98922



## Abstract

As part of the Reproductive Ecology and Domestication Monitoring and Evaluation program in the Yakima/Klickitat Fishery Project (YKFP), we compared upper Yakima River hatchery and wild origin spring chinook returns in 2002 over an array of fitness related traits characterizing each group's gametes and progeny ("button up" stage fry).

**Fecundity:** Age-4 hatchery females (3,984 eggs) were 2% less fecund than wild origin females (4,067 eggs), although this was not a significant difference. Age-5 wild origin females (4,729 eggs) were significantly more fecund on average than age-4 females.

**Female Size/Fecundity Relationships:** Fecundity and female body size were positively correlated in both hatchery and wild origin age-4 females. The fecundity/length and fecundity/weight slopes of age-4 hatchery and wild origin females were not significantly different (common slopes=  $942 \text{ eggs} \cdot [\text{kg body weight}]^{-1}$  and  $145 \text{ eggs} \cdot [\text{cm POHP}]^{-1}$ ). Wild age-5 females also had weaker, positive correlations between female body size and fecundity that were significantly shallower compared to age-4 females linear relationships, producing approximately half as many eggs per unit body size ( $531 \text{ eggs} \cdot [\text{kg body weight}]^{-1}$  and  $77 \text{ eggs} \cdot [\text{cm POHP}]^{-1}$ ). Including body weight, mean egg weight and POHP in multi-variate fecundity regression equations significantly increased the amount of variation explained and improved the precision of fecundity estimates.

**Egg Weight:** There was a significant difference between age-4 hatchery (0.180 g) and wild (0.188 g) origin mean egg weights. Eggs of age-5 wild origin females (0.223 g) were significantly heavier than age-4 females. There were weak positive correlations between egg weight and female POHP and body weight. The relationship between egg size and fecundity was negative, weak and significant only in wild age-4's.

**Female Reproductive Effort:** Female Reproductive Effort (RE), the ratio of the weight of gametes to total body weight, of age-4 hatchery females (mean=0.198) was equal to wild females (mean=0.197), while age-5 wild females (mean=0.179) had lower RE. The difference between age-4 and -5 groups was not statistically significant.

**Egg-to-Fry Survival and Developmental Abnormalities:** There was no significant difference in egg-to-fry viability of eggs of hatchery (mean viability =0.91) and wild (mean viability =0.91) origin females. Both hatchery (mean=0.003) and wild (mean=0.004) origin fish had very low proportions of abnormally developing fry with no significant difference between groups.

**Fry Size:** Wild fry (33.6 mm and 0.33 g) were larger than hatchery fry (33.0 mm and 0.31 g), but the differences were not significant. There were strong positive relationships between fry size and egg weight for both wild and hatchery origin females. Thus, much of the difference in fry size can be explained by the fact that wild females had larger eggs than hatchery females. Wild and hatchery fry fork length/egg weight relationships explained  $\geq 32\%$  of the total variation and the fry body weight/egg weight relationships

explained  $\geq 72\%$  of the total variation. ANCOVA indicated that hatchery and wild fry slopes were not significantly different. There were weak positive female body size/fry size relationships. Female body weight had more influence on fry size than female POHP, but it only explained at most 14% of the total variation in fry size.

**Emergence Timing:** This research effort was initiated in 2002. Emergence chambers were installed at CESRF and approximately 100 eyed eggs from each of 32 females, 16 hatchery and 16 wild, were placed into the units. Fry emergence was monitored daily from February 22, 2003 through April 21, 2003. Emerging fry were enumerated and sampled for weight and length.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

## Introduction

A critical aspect of assessing success in the Yakima/Klickitat Fishery Project's (YKFP) spring chinook (*Oncorhynchus tshawytscha*) program is evaluating traits that determine natural production and to compare hatchery and wild origin fish across these traits. That is because project success is defined as increasing natural production and harvest opportunities, while keeping adverse ecological interactions and genetic impacts within acceptable bounds (Busack et al. 1997). Significant changes in locally adapted traits due to hatchery influences, whether of genetic or environmental origin, will likely be maladaptive, resulting in reduced population productivity and fitness (Taylor 1993; Hard 1995). Naturally spawning hatchery fish have been shown to be less reproductively successful than wild fish in some studies (Resenbichler and McIntyre 1977; Chilcote et al. 1986; Leider et al. 1990; Schroder et al. 2003) particularly in populations that have experienced multiple years of domestication (see the review in Schroder et al. 2002). Traits such as fecundity (Healey and Heard 1985; Fleming and Gross 1990; Beacham and Murray 1993), emergent fry size and fry energy reserves (Thorpe et al. 1984; Hendry et al. 2001), egg incubation rates, and emergence timing (Beacham and Murray 1993; Quinn et al. 1995) affect reproductive success and fitness and often reflect local adaptations (Taylor 1991; Hendry et al. 1998; Quinn et al. 2001). Other traits, such as the size and number of eggs produced per unit body size or the biomass of gametes per unit body size, indicate how populations have responded to local selection forces and have optimized allocation of energy between somatic growth, gametes, migration, competition and mating (Heath et al. 1999; Kinnison et al. 1998; Kinnison et al. 2001).

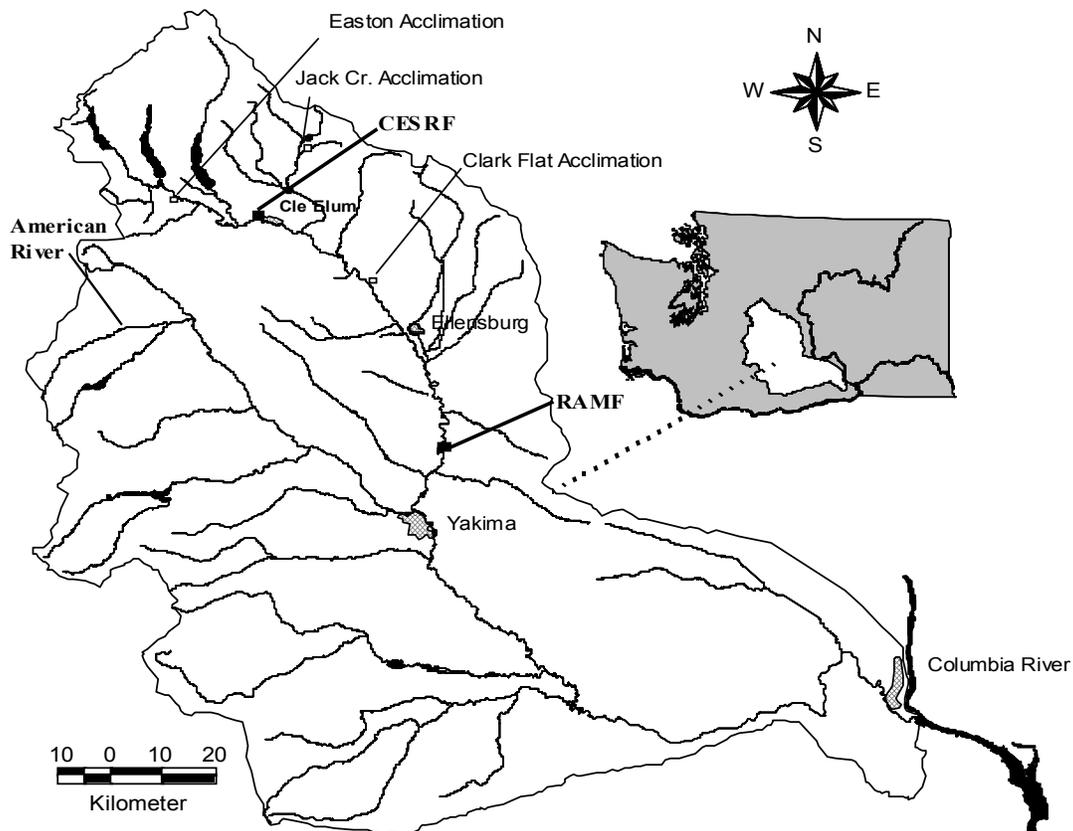
In this chapter, we make comparisons between hatchery origin fish from the Cle Elum Supplementation Research Facility (CESRF) and upper Yakima River wild origin spring chinook returning in 2002 over a suite of traits affecting fitness and reproductive success. These include fecundity, female body size/fecundity relationships, female reproductive effort, egg size, egg-to-fry viability, fry size, fry length/egg size relationships, female size/fry size relationships, and occurrences of developmental abnormalities. We describe new work designed to estimate and compare emergent fry traits.

Tracking fitness related traits over time is also an important aspect of monitoring domestication effects to determine whether divergence in traits is occurring between the supplemented naturally spawning population, a hatchery control line established in 2002, and a wild Naches basin control population (excluding the American River; see Busack et al. 2002). Thus, we will expand our genetic trait comparisons to Naches females in future reports.

## Methods and Materials

### Study Populations

The upper Yakima River is a tributary to the Yakima River, which discharges into the Columbia River (Fig. 1). Monitoring of the wild upper Yakima River population has occurred annually at Roza Adult Monitoring Facility (RAMF) since wild origin broodstock collection first began in 1997. The first hatchery reared cohort began returning in 2000 as anadromous age-3 jacks, 2001 as age-4 adults, and age-5 adults in 2002. However, sexually mature non-anadromous age-2 hatchery origin males have been observed on redds within 5 months after their release beginning in 1999 (Pearsons et al. 2003). In addition, precocious males have been video taped spawning with adult pairs in the upper Yakima River (Knudsen and Schroder, pers. observations) and have successfully produced offspring in competition with naturally spawning adult males (Schroder et al. 2002; Schroder et al. 2003). Thus, it is likely that in the upper Yakima River wild population introgression of genes from hatchery origin fish began in 1999, the first year of CESRF hatchery releases.



**Figure 1. Yakima River basin showing the upper Yakima River, Roza Adult Monitoring Facility (RAMF), and the Cle Elum Supplementation and Research Facility (CESRF).**

Length, weight, and age data are collected from a subsample of returning spring chinook as they pass upstream through RAMF approximately 1 to 5 months prior to reaching full maturity. For a full description of the sampling, collection, and processing of hatchery and wild origin returns at RAMF see Knudsen et al. (2002a). A subsample of wild and hatchery origin fish are collected from throughout the run and taken to the CESRF. Data collected from wild origin fish selected for broodstock are used to represent the wild population's adult phenotypic and demographic traits, as well as, the following reproductive traits: total gamete mass weight (females), egg weight, female reproductive effort, fecundity, viability, incidence of abnormally developing fry, fry size and fry emergence timing. In 2002, there were 631 wild origin fish collected for broodstock and reproductive success studies and 120 hatchery origin fish. Of these, 1 age-3, 231 age-4 and 10 age-5 wild origin females and 63 age-4 and 2 age-5 hatchery origin females were sampled for fecundity, reproductive effort, gamete mass, and egg weight. Comparisons to the hatchery age-5 group were considered uninformative due to low statistical power and small sample size and are not reported.

## Traits

### Total Gamete Mass, Egg Weight, Fecundity and Female Reproductive Effort

Total gamete mass and mean egg weights were collected as females were artificially spawned at CESRF. A large portion of the ovarian fluid was drained off prior to a female's total egg mass being weighed to the nearest 0.1 g. A subsample of approximately 30-50 eggs was then collected, weighed to the nearest 0.01 g, and the number of eggs in the subsample counted and used to calculate the mean weight of "green" eggs (eggs unexposed to water). A gravimetric estimate of fecundity was then calculated by dividing the total gamete mass by the mean green egg weight. Since it is not possible to drain off all ovarian fluid, gravimetric fecundity estimates are often biased, overestimating fecundity. In order to adjust our estimates of fecundity for this bias we multiplied them by 0.9618, a correction factor developed in 2001 based on hand counts of 19 female egg lots (Knudsen et al. 2002b).

The linear relationship between fecundity and female body weight, POHP length and egg size was estimated and comparisons of the slopes of the body size/fecundity regressions were made using ANCOVA. In addition, body weight, POHP length and egg size were examined as predictors of fecundity in a multivariate regression analysis.

We compared egg weight distributions of age-4 hatchery and wild origin females using ANOVA. Gametes from 10 wild and 2 hatchery 5-year old females were sampled in 2002.

Reproductive effort (RE) was calculated for hatchery and wild origin females spawned at CESRF. This metric describes the proportion of a female's total biomass represented by gametes and is calculated by dividing the total egg mass weight (drained of ovarian fluid) by the total body weight including gametes and ovarian fluid. Each year a few females held at CESRF have significant proportions of unripe, overripe, injured, or

abnormally developing eggs. We assumed these were primarily due to females being selected for spawning either too early or too late and/or from injuries incurred during handling, transfer and holding. Egg retention rates in wild naturally spawning Yakima River spring chinook females are generally very low (M. Johnston, YN, unpublished data; S. Young, WDFW, unpublished data). While broodstock are being held, particularly in the latter weeks of the spawning season, significant numbers of eggs are observed on the bottom of the adult holding raceway indicating that some females release gametes prior to artificial spawning. Females with RE values below 0.15 (24 of 333 total hatchery and wild origin females in 2002) were considered to have a significant portion of either under- or over-developed, injured, or lost eggs prior to being spawned and consequently their fecundity and RE values were excluded from our analyses. For our purpose, estimating fecundity of naturally spawning females, this seemed reasonable. If our intent had been to estimate egg production of broodstock for artificial production, we would have included these females, treating their egg loss as simply part of the operational “costs” associated with artificial production. It is possible we excluded a few females that would have had naturally occurring RE values less than 0.15.

#### Factorial Crosses: Egg-to-Fry Viability, Developmental Abnormalities and Fry Size

The standard spawning protocol at CESRF is to spawn the fish in a series of factorial crosses (Busack et al. in prep) typically consisting of 3 females and 3 males, creating 9 single pair matings. In 2002, all factorial crosses for this study were *inter se* matings of 3 females and 3 males of the same origin (Table 1). On average, 247 eggs (range: 206 to 285) per female were placed into a dry 1 L beaker and 1 cc of milt from the respective male was dripped over the eggs using a 3 ml syringe. The gametes were then activated by adding 200 ml of well water and gently swirling the contents to insure thorough mixing. After a minimum of 2 minutes post-activation, the eggs were decanted and placed into individual incubation containers called isolettes and labeled with the female and male’s origin and individual identification numbers. The isolettes were then placed into an Iodiphore bath for approximately 45 minutes. An isobucket, containing 3 isolettes from one female, was used to incubate eggs the eyed egg stage. Eggs were then shocked, mortalities removed, and the isolettes transferred to Heath trays for final incubation to the post-hatching yolk absorption or “button up” stage.

Table 1. Schematic of two 3x3 *inter se* factorial crosses resulting in 9 single pair matings for each type.

|               |                 |     | Males types |     |     |                 |     |     |
|---------------|-----------------|-----|-------------|-----|-----|-----------------|-----|-----|
|               |                 |     | Wild origin |     |     | Hatchery origin |     |     |
|               |                 |     | W♂1         | W♂2 | W♂3 | H♂1             | H♂2 | H♂3 |
| Females types | Wild origin     | W♀1 |             |     |     | No matings      |     |     |
|               |                 | W♀2 |             |     |     |                 |     |     |
|               |                 | W♀3 |             |     |     |                 |     |     |
|               | Hatchery origin | H♀1 | No matings  |     |     |                 |     |     |
|               |                 | H♀2 |             |     |     |                 |     |     |
|               |                 | H♀3 |             |     |     |                 |     |     |

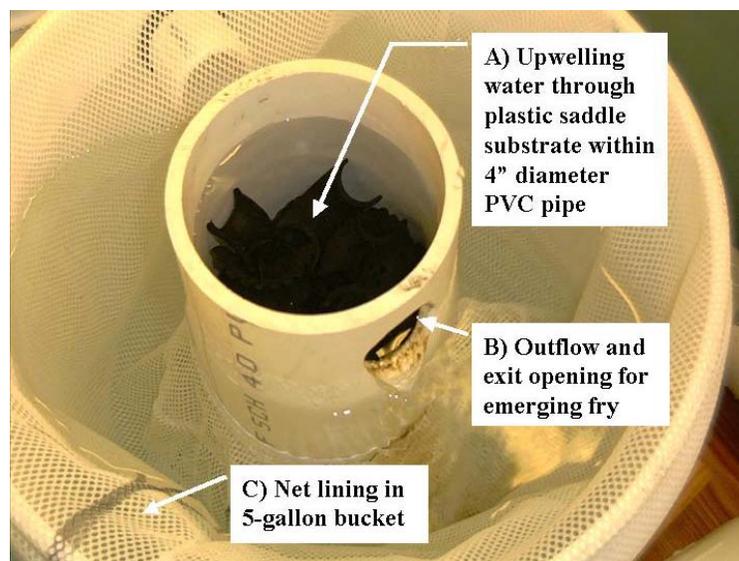
Isolettes were sampled twice: once, at the eyed egg stage just after shocking when all viable and nonviable eggs were counted and again, just after yolk absorption, when any additional mortalities were counted. Deformities and abnormalities (e.g. scoliosis, missing eyes, Siamese twinning, inappropriate fin development, or enlarged yolk) were enumerated during the final sampling. Because the viability and deformity data were highly skewed and non-normally distributed, we analyzed them using a Kruskal-Wallis 1-way ANOVA to estimating Origin (Hatchery/Wild) effects (Zar 1984).

Fork length and body weight were measured on five individual fry from one single-pair mating from each female within a factorial cross. Thus, not all males are represented in the sample. However, since we were monitoring fry size at the yolk-absorption stage, maternal effects should overwhelm male effects (Iwamoto et al. 1984; Heath et al. 1999). Fry were anesthetized and blotted dry prior to being weighed. Wild and Hatchery origin fry size (mean weights and lengths from the 5 fish samples) was compared using ANOVA.

### Emergence Fry Traits

We selected 16 hatchery and 16 wild females representing a broad range of egg size for use comparing hatchery and wild emergent fry traits. We suspected these traits might be influenced by egg size. Mean, standard deviation, and range of egg sizes, and other descriptive statistics, of females included in the study are given in Table 2. Compare developmental condition at emergence or  $K_D$  (Bams 1970) and emergence timing.

Approximately 100 “eyed” eggs from a female were placed into a PVC chamber filled with plastic saddles as incubation substrate on November 25, 2002 (Fig. 2).



**Figure 2.** Fry emergence unit showing A) the plastic saddle substrate within the PVC pipe, B) the fry exit opening, and C) the net lined 5 gallon holding bucket. An opaque cover was placed over the open end of the PVC pipe containing the substrate.

Females were randomly assigned to chambers. Within each chamber, upwelling water flowed at the rate of approximately 173 ml/5 seconds. Flows were checked and adjusted every other day, as needed. As fry developed, they began volitionally moving up out of the substrate and exited out an opening in the incubation chamber, dropping into a screened net-lined 5 gallon bucket (Fig. 2). The buckets were checked daily and fry enumerated and sampled for weight and fork length used to calculate  $K_D$ . Daily monitoring of emergence began on February 22, 2003 and continued until April 21.

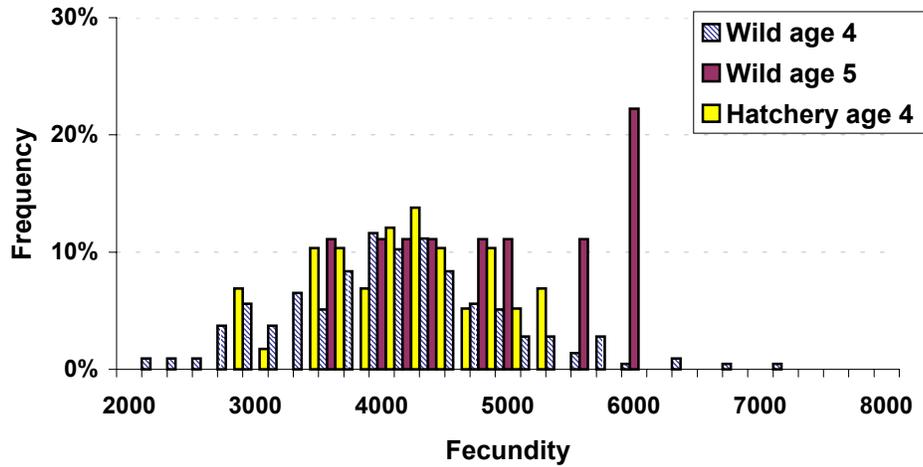
| Origin   | Trait               | Mean  | sd    | Median | cv   | Range  |
|----------|---------------------|-------|-------|--------|------|--------|
| Hatchery | POHP (cm)           | 59.0  | 4.3   | 59.3   | 7.3  | 15.0   |
|          | Body weight (kg)    | 3.5   | 0.7   | 3.6    | 21.0 | 2.3    |
|          | Egg mass (g)        | 675.3 | 199.1 | 713.4  | 29.5 | 703.6  |
|          | Egg weight (g)      | 0.180 | 0.029 | 0.178  | 16.1 | 0.112  |
|          | Fecundity           | 3744  | 948   | 3759   | 25.3 | 3727   |
|          | Reproductive effort | 0.190 | 0.034 | 0.193  | 18.0 | 0.133  |
| Wild     | POHP (cm)           | 62.2  | 5.1   | 61.1   | 8.2  | 18.3   |
|          | Body weight (kg)    | 4.2   | 1.2   | 4.0    | 28.5 | 4.3    |
|          | Egg mass (g)        | 806.8 | 256.4 | 738.1  | 31.8 | 1084.0 |
|          | Egg weight (g)      | 0.189 | 0.034 | 0.187  | 17.8 | 0.132  |
|          | Fecundity           | 4223  | 784   | 4055   | 18.6 | 3015   |
|          | Reproductive effort | 0.194 | 0.027 | 0.201  | 14.2 | 0.097  |

## Results

### Fecundity and Fecundity/Female Size Relationship

Fecundity distributions for age-4 hatchery and wild and age-5 wild females selected for broodstock are shown in Figure 3. Mean hatchery age-4 fecundity was 3,984 (n=54; sd=654), wild age-4 fecundity was 4,067 (n= 215; sd=854), and wild age-5 fecundity was 4,729 (n= 9; sd=856). A comparison of the three groups resulted in significant differences between the age-4 and -5 groups (Tukey multiple-comparisons test  $p<0.05$ ), but not between the hatchery and wild age-4's ( $p=0.77$ ).

There was a significant positive correlation between fecundity and POHP length and body weight at spawning in both hatchery and wild origin age-4 females (Table 3). In an ANCOVA, there was no significant difference between the slopes of the two regressions (POHP,  $p=0.820$  equivalent slopes; Body weight,  $p=0.837$  equivalent slopes). In comparison to age-4's, age-5 wild origin females had a weaker, shallower



**Figure 3. Fecundity distributions of hatchery and wild origin females in 2002. All females have reproductive effort values greater than 0.15.**

| Table 3. Results of four linear regressions estimating fecundity using either female POHP length or female body weight for age-4 wild of hatchery origin females. |          |             |               |                |                            |
|---|----------|-------------|---------------|----------------|----------------------------|
| Origin Age  | Effect   | Coefficient | Regression SE | R <sup>2</sup> | Regression <i>p</i> -value |
| Wild Age 4 (n=215)  | Constant | 344.8       | 605.7         | 0.499          | <0.001                     |
|   | Body Wt  | 958.3       |               |                |                            |
|   | Constant | -5176.3     | 677.4         | 0.373          | <0.001                     |
|   | POHP     | 150.9       |               |                |                            |
| Wild Age 5 (n=9)  | Constant | 1596.2      | 780.3         | 0.170          | 0.149                      |
|   | Body Wt  | 530.6       |               |                |                            |
|   | Constant | -733.1      | 882.2         | 0.000          | 0.487                      |
|   | POHP     | 76.5        |               |                |                            |
| Hatchery Age 4 (n=58)   | Constant | 577.1       | 378.2         | 0.666          | <0.001                     |
|   | Body Wt  | 928.8       |               |                |                            |
|   | Constant | -4615.5     | 443.1         | 0.541          | <0.001                     |
|   | POHP     | 144.7       |               |                |                            |

fecundity/body size relationship (Figs. 4 and 5). In the ANCOVA, slopes of age-4 and –5 year olds were not significantly different (fecundity/body weight  $p=0.09$ ; fecundity/POHP  $p=0.53$ ). However, because there were only 9 age-5 females, the test was not statistically powerful. We estimated age-4 females (hatchery and wild combined) had fecundity/body size slopes of  $942 \text{ eggs} \cdot (\text{kg body weight})^{-1}$  and  $145 \text{ eggs} \cdot (\text{cm POHP})^{-1}$ , while wild origin age-5 females had slopes approximately 50% lower:  $531 \text{ eggs} \cdot (\text{kg body weight})^{-1}$  and  $77 \text{ eggs} \cdot (\text{cm POHP})^{-1}$ .

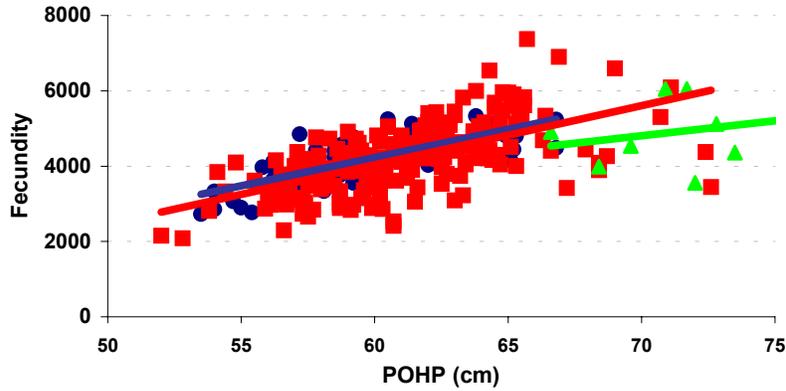


Figure 4. Linear relationship between CERSF POHP length and fecundity for hatchery age-4(●), wild age-4 (■) and wild age-5 (▲) origin upper Yakima River spring chinook in 2001.

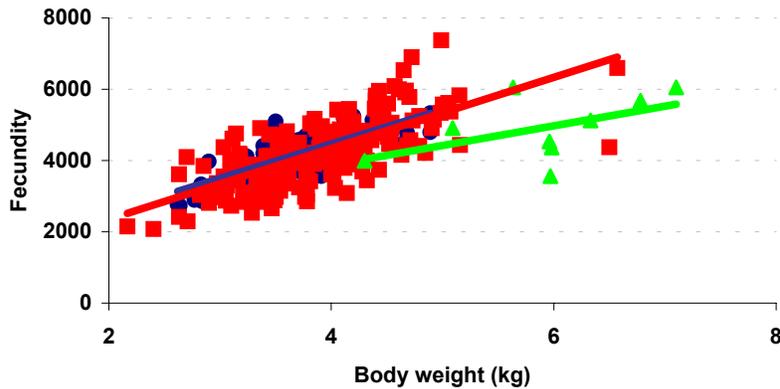


Figure 5. Linear relationship between CERSF body weight (BW) and fecundity for hatchery age-4(●), wild age-4(■) and wild age-5 (▲) origin upper Yakima River spring chinook in 2001.

In order to develop a more precise estimate of fecundity, particularly for use in estimating the fecundity of females used in the spawning channel, we used multiple linear regression including female body weight, POHP length and mean egg size to estimate fecundity (Table 4). Mean egg size and body weight were significant variables in all regressions ( $p < 0.02$ ), while POHP explained less variation ( $p$ -values ranged from 0.08 to 0.97). Including body weight, egg weight and POHP in the fecundity regressions explained 67-77% of the total variation with SE's of 347 to 489, while any one of the three variables alone explained 0 to 67% of the total variation with SE's ranging from 378 to 882.

Table 4. Multiple regression results using mean egg weight, POHP length and female body weight to estimate fecundity. The significance of each variable's contribution to the overall regression equation is given (*p*-value), as is the regression's standard error (SE) and adjusted R<sup>2</sup>.

| Origin                   | Effect   | Coefficient | <i>p</i> -value | SE    | Adjusted R <sup>2</sup> |
|--------------------------|----------|-------------|-----------------|-------|-------------------------|
| Wild<br>Age 4<br>(n=214) | Constant | 4198.5      | <0.001          | 412.6 | 0.767                   |
|                          | Egg Wt   | -17162.0    | <0.001          |       |                         |
|                          | POHP     | -26.6       | 0.084           |       |                         |
|                          | Body Wt  | 1224.8      | <0.001          |       |                         |
| Wild<br>Age 5<br>(n=9)   | Constant | 12921.8     | 0.060           | 489.3 | 0.673                   |
|                          | Egg Wt   | -20468.2    | 0.018           |       |                         |
|                          | POHP     | -168.2      | 0.117           |       |                         |
|                          | Body Wt  | 1415.6      | 0.011           |       |                         |
| Hatchery<br>(n=58)       | Constant | 2202.3      | 0.117           | 347.1 | 0.719                   |
|                          | Egg Wt   | -9284.5     | 0.001           |       |                         |
|                          | POHP     | -1.3        | 0.968           |       |                         |
|                          | Body Wt  | 967.9       | <0.001          |       |                         |

### Egg Weight

Based on egg weight data from 4-year old females spawned at CESRF in 2002 (Fig. 6), hatchery females (mean=0.180 g; n=63) had significantly smaller eggs than wild (mean=0.188 g; n=231) females (1-way ANOVA; *p*=0.034). Age-5 wild origin female's (mean=0.223 g; n=10) eggs were significantly larger than age-4 female's (Tukey multiple comparisons test; *p*<0.01). There was no strong relationship between POHP length and egg weight in 2002 (Fig. 7). The relationship was not significant in hatchery age-4 or wild age-5 females (*p*>0.80), but was in wild females (*p*=0.03). However, POHP length explained just 2% of the total variation in egg weight. Only wild age-4 females showed a significant relationship between body weight and egg weight (*p*<0.001). The weak positive relationship explained was only 6% of the total variation (Fig. 8).

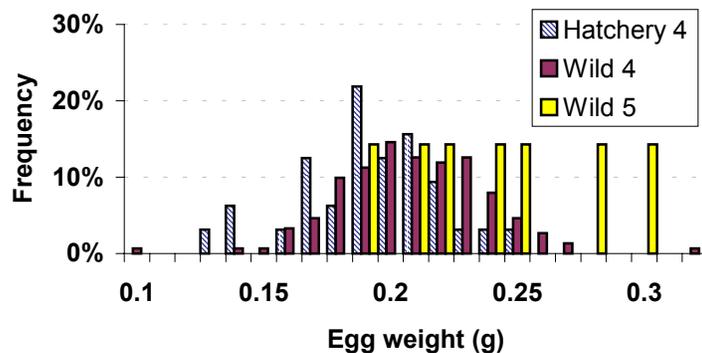


Figure 6. Egg weight (g) distributions of age-4 hatchery (n=32), age-4 wild (n=151) and age-5 (n=7) wild origin females in 2002.

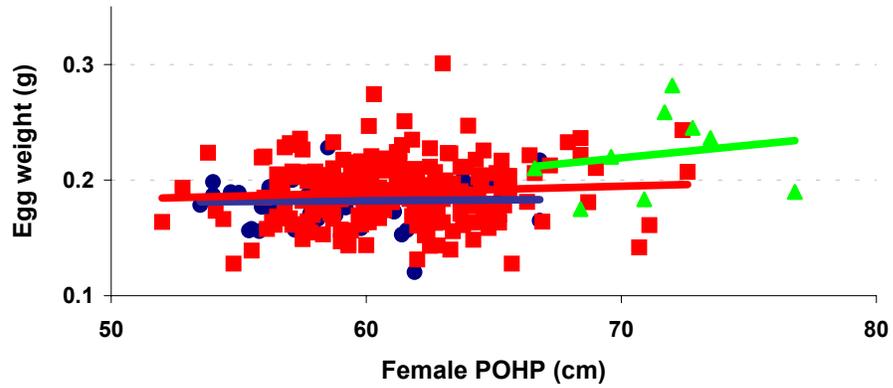


Figure 7. Linear relationship between CERSF female POHP length and egg weight for age-4 hatchery (●), age-4 wild (■) and age-5 wild (▲) origin females in 2002.

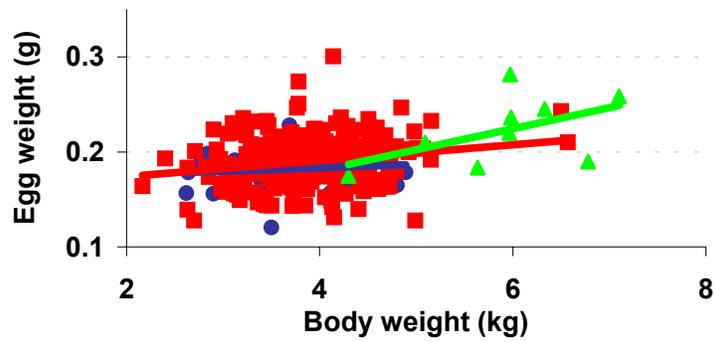


Figure 8. Linear relationships between female body weight and "green" individual egg weight for hatchery age-4 (●), wild age-4 (■) and wild age-5 (▲) origin females in 2002.

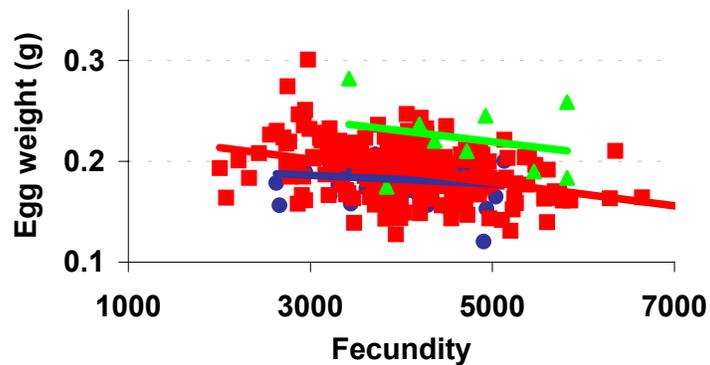


Figure 9. Linear relationship between fecundity and "green" individual egg weight for hatchery age-4 (●), wild age-4 (■) and wild age-5 (▲) origin females in 2002.

The relationship between egg weight and fecundity was negative in all groups of females (Fig.9). The relationship was statistically significant for only wild age-4 females ( $p<0.01$ ) and was weak, explaining only 13% of the total variation in egg weight.

### Reproductive Effort

Female Reproductive Effort (RE), the ratio of the total weight of a female's gametes to total body weight, represents the proportion of total somatic growth allocated to producing gametes. The RE of age-4 hatchery females (mean=0.198; n=63) was nearly identical to wild females (mean=0.197; n= 230), while wild age-5 wild females had lower mean RE (mean=0.179; n= 10). The three groups were not significantly different (ANOVA;  $p=0.173$ ).

### Relative Fecundity

Relative Fecundity (RF) standardizes fecundity to a “per unit body size” metric or  $\text{eggs} \cdot (\text{kg body weight})^{-1}$ . Wild age-4 females (Wild RF= 1049  $\text{eggs} \cdot (\text{kg body weight})^{-1}$ ) had RF values that were greater than hatchery females (1089  $\text{eggs} \cdot (\text{kg body weight})^{-1}$ ), but not significantly greater (Tukey multiple comparisons  $p=0.146$ ). Age-5 wild female's mean RF (807  $\text{eggs} \cdot (\text{kg body weight})^{-1}$ ) was significantly lower than both hatchery and wild origin age-4's (Tukey  $p<0.01$ ).

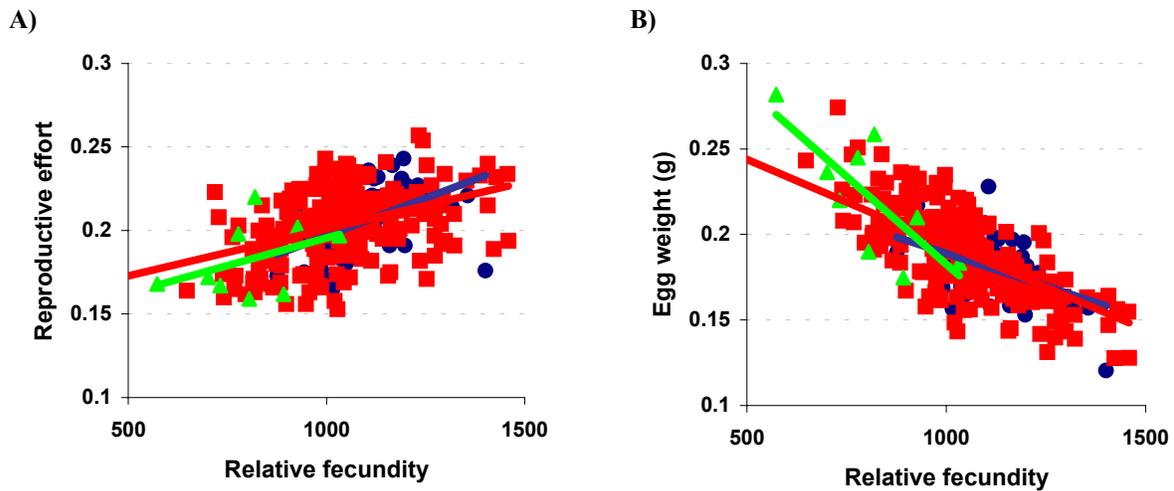


Figure 10. Relationship of A) reproductive effort and B) egg weight to relative fecundity ( $\text{eggs}/\text{kg body weight}$ ) for age-4 hatchery (●), age-4 wild (■), and age-5 wild females (▲) females in 2002.

## Relative Fecundity vs. Egg Weight and RE

Regressing egg weight or RE against RF illustrates how females manage the tradeoffs between somatic growth and gametes or egg size as RF changes. The linear relationship between RE and RF and egg weight for hatchery and wild origin females are shown in Figures 10A and 10B. RE and RF were positively correlated for age-4 hatchery ( $r^2=0.21$ ;  $p<0.01$ ) and wild ( $r^2=0.17$ ;  $p<0.01$ ) origin females and there was no significant difference between their slopes ( $p=0.18$ ). Age-5 wild females exhibited no significant correlation ( $p=0.27$ ). Egg weight and RF were negatively correlated across all female groups ( $r^2>0.20$ ;  $p<0.01$ ; Fig. 10B). Age-5 wild females had the steepest slope, but the ANCOVA results indicated no significant difference between the three slopes ( $p=0.531$ ).

## Egg Viability and Developmental Abnormalities

There was no significant Origin effect when egg viability distributions of hatchery (mean viability =0.910; n=33) and wild (mean viability =0.908; n=35) origin females were compared using a Kruskal-Wallis one-way ANOVA ( $p=0.127$ ). Abnormally developing fry were rare in both hatchery and wild samples, occurring in less than 0.5% of the eggs on average (Fig 11). Mean percentages of hatchery and wild fry with abnormalities were 0.32% and 0.38%, respectively, which was not significantly different (Kruskal-Wallis 1-way ANOVA;  $p=0.94$ ).

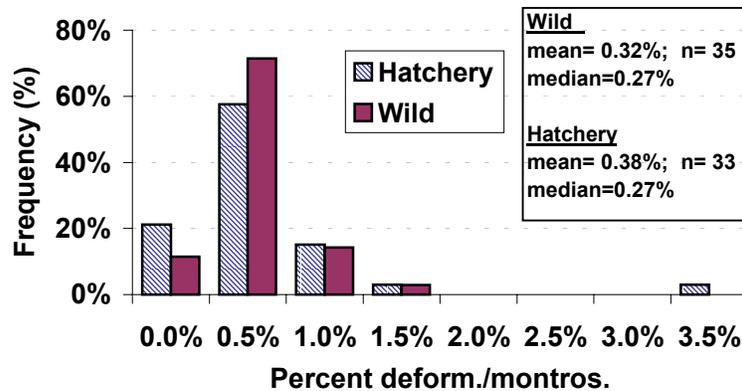


Figure 11. Frequency distribution of deformities and monstrosities in 2002 hatchery and wild fry.

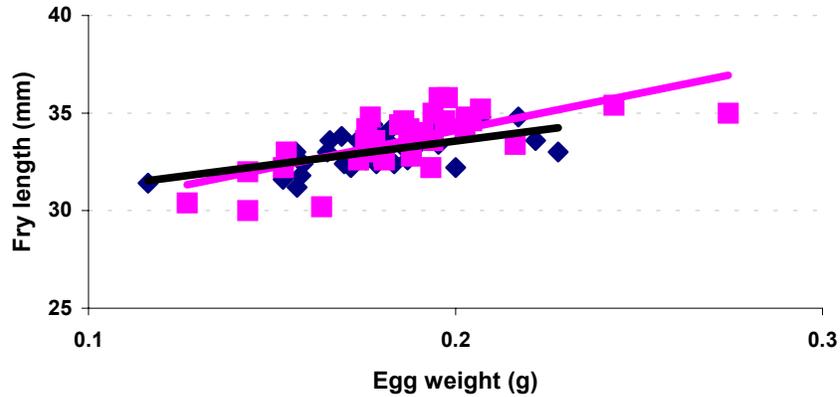


Figure 12. Relationship between fry length and egg weight for hatchery (◆; n=35) and wild (■; n=33) origin spring chinook from the 2002 brood.

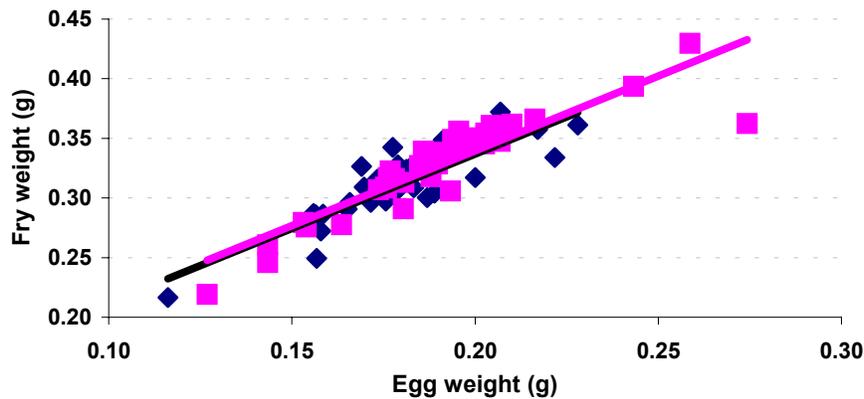


Figure 13. Relationship between fry weight and egg weight for hatchery (◆; n=35) and wild (■; n=33) origin spring chinook from the 2002 brood.

### Fry Size

Wild fry (33.6 mm and 0.33 g) were larger than hatchery fry (33.0 mm and 0.31 g), but the difference was not quite significant at the  $\alpha=0.05$  level for either length ( $p=0.062$ ) or weight ( $p=0.089$ ). Egg weight was positively correlation with fry length ( $r^2 \geq 0.32$ ;  $p < 0.01$ ; Fig. 12) and fry weight ( $r^2 \geq 0.72$ ;  $p < 0.01$ ; Fig. 13). Results from ANCOVA indicated that hatchery and wild fry have equal fry weight/egg weight and fry length/egg weight slopes ( $p \geq 0.29$ ). Hatchery and wild fry also had equivalent fry length/fry weight slopes ( $p=0.741$ ; Fig. 14).

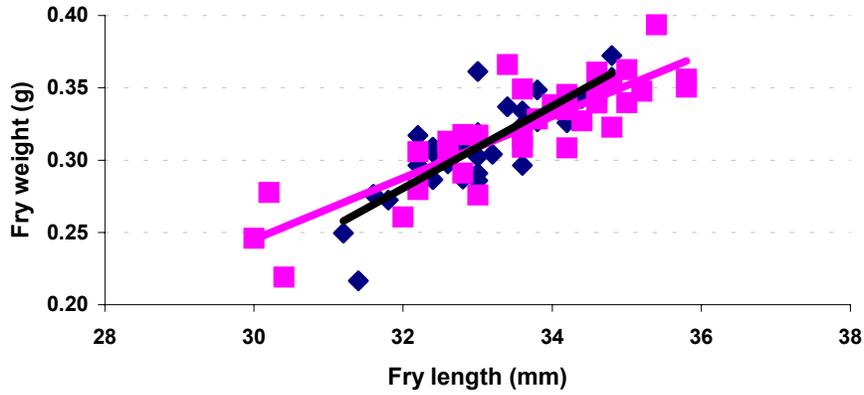


Figure 14. Comparison of hatchery (◆) and wild (■) origin fry weight (FW) versus fry fork length (FL) for progeny of 2002 upper Yakima River spring chinook.

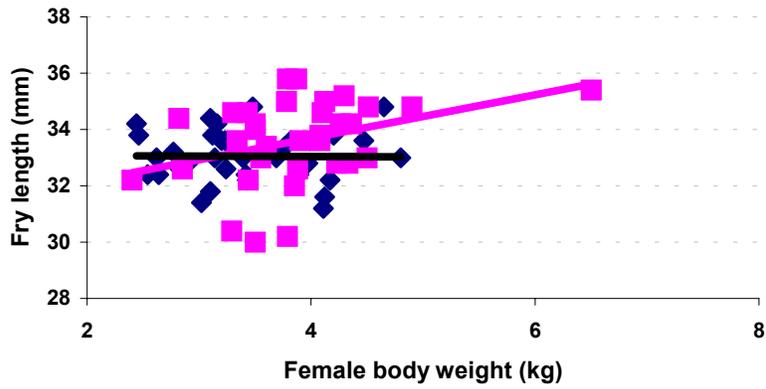


Figure 15. Linear relationship between female body weight and fry fork length in hatchery (◆) and wild (■) origin spring chinook in 2002.

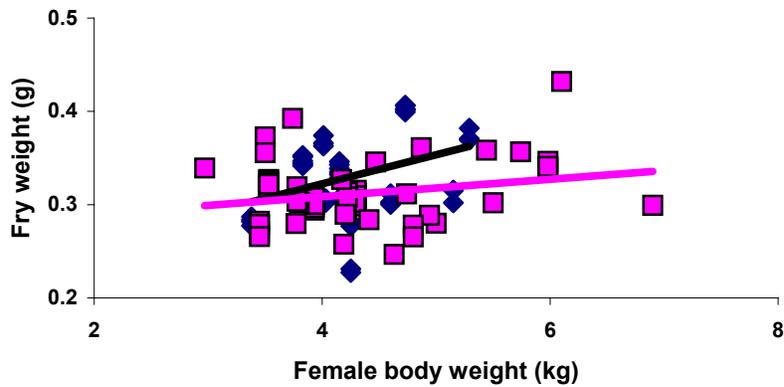


Figure 16. Linear relationship between female body weight and fry weight in hatchery (◆) and wild (■) origin spring chinook.

There were weak positive correlations between female body weight and fry size (Table 5; Fig. 15 and 16), but only 6 to 14% of the total variation was explained by the regressions. Wild females exhibited the only significant female POHP/Fry size relationship ( $p=0.04$ ), but it explained only 7% of the total variation in fry length. Thus, female body weight had a stronger influence on fry size than female POHP, but only explained at most 14% of the total variation in fry size.

### Fry Emergence Timing

During the period this report covers (April 1, 2002 to March 31, 2003) our monitoring of fry emergence was still being completed and no analyses of data have been done.

| Table 5. Linear relationships between female body weight (FW) and POHP length (FL) to fry fork length (FryLn) and fry body weight (FryBW) by origin for upper Yakima River spring chinook. |          |                |         |    |                              |
|--|----------|----------------|---------|----|------------------------------|
| Relationship   | ♀ Origin | R <sup>2</sup> | p-value | n  | Linear equation              |
| FW by FryLn  | Hatchery | 0.089          | 0.104   | 44 | FryLn = (FW*0.558) + 32.40   |
|  | Wild     | 0.101          | 0.007   | 63 | FryLn = (FW*0.403) + 32.65   |
| FW by FryBW  | Hatchery | 0.135          | 0.039   | 44 | FryBW = (FW*0.025) + 0.222   |
|  | Wild     | 0.058          | 0.058   | 63 | FryBW = (FW*0.010) + 0.269   |
| FemL by FryLn  | Hatchery | 0.026          | 0.294   | 44 | FryLn = (FemL*0.090) + 29.25 |
|  | Wild     | 0.067          | 0.040   | 63 | FryLn = (FemL*0.063) + 30.40 |
| FemL by FryBW  | Hatchery | 0.051          | 0.142   | 44 | FryBW = (FemL*0.004) + 0.055 |
|  | Wild     | 0.018          | 0.290   | 63 | FryBW = (FemL*0.001) + 0.240 |

## Discussion

Any differences in heritable traits of CESRF hatchery and upper Yakima River wild origin fish, would have to be due to the effects of a single generation of domestication driven by either unintentional directional selection and/or relaxation of natural selection pressures in the hatchery. Trait differences can also have a non-genetic basis, caused by phenotypic plasticity due to environmental variation (Riddell 1986). A common example of this is larger size and later release of hatchery fish relative to wild

conspecifics. This typically occurs because larger fish released later often experience higher survival (Bilton et al. 1982). They are larger at release than naturally rearing juveniles because of the hatchery environment (rearing/feed regime) and outmigrate later due to human intervention (release timing). Thus, these trait differences would exist even if the two groups shared common parents. However, these environmentally induced differences can cause changes in adult phenotypic traits such as reduced age at maturity (Beatty 1996) and size-at-return in hatchery chinook (Unwin and Glova 1997) and coho salmon (Bilton et al. 1982). In reality, observed trait differences are likely to be due to complex combinations of both environmental and genetic factors affecting trait expression that will vary in intensity from year to year. The YKFP has begun implementation of a domestication study (Busack et al. 2002) to help identify the magnitude of the genetic component in any observed trait differences.

In the 2001 returns, we observed a significant decrease in fecundity in hatchery fish relative to wild fish as a direct consequence of reduced hatchery size-at-age (Knudsen et al. 2002a). Hatchery fish were also smaller than wild fish in 2002 and had lower fecundity, but the difference was not statistically significant. This is because hatchery and wild fish had similar RE means, but hatchery egg weight was 4% lower than wild egg weight in 2002 resulting in higher relative fecundity ( $\text{eggs} \cdot (\text{kg body weight})^{-1}$ ). Since hatchery females had higher mean RF ( $1089 \text{ eggs} \cdot (\text{kg body weight})^{-1}$ ) than wild females ( $1049 \text{ eggs} \cdot (\text{kg body weight})^{-1}$ ), this compensated for their smaller size, resulting in no significant fecundity difference. Heath et al. (2003) found that females from captive brood spring chinook populations produced smaller eggs than wild females, which they attributed to a combination of relaxation of natural selection pressures for larger egg size and intentional selection for higher fecundity. Heath et al. also found that egg size was positively correlated with fry survival. However, we found no evidence of a similar significant correlation in an analysis of log-log transformed egg-to-fry survival vs egg weight (Fig. 17).

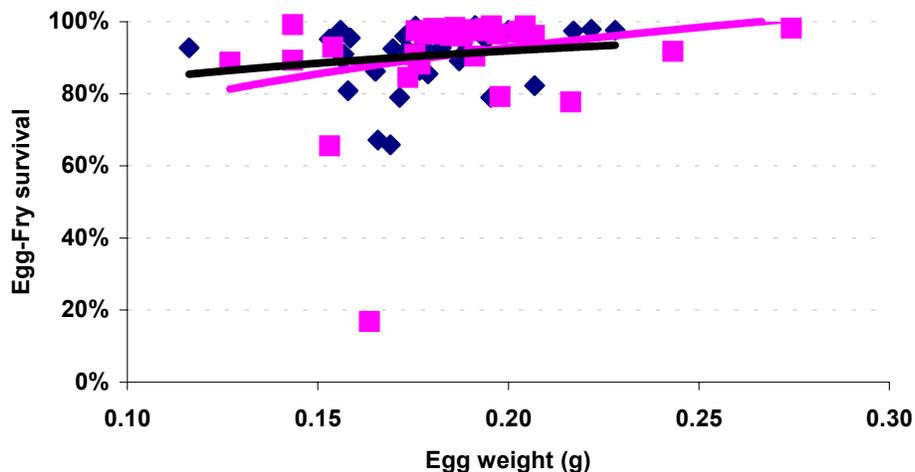


Figure 17. Log-log transformed linear regressions of egg weight and egg-to-fry survival for both hatchery (◆) and wild (■) females were not significantly different from 0.0 ( $p > 0.253$ ).

The allocation of energy between gamete production, somatic growth and behavior affects female fitness. There are significant trade offs made between energy budgeted toward gametes and other “bins” such as migration, body size, secondary sexual characteristics, competition and nest guarding (Kinnison et al 2001) and the allocation between all “bins” should coevolve under selection pressures so that lifetime reproductive success will be maximized (Pianka 1976; Roff 1988). For a naturally spawning fish, shifting gamete biomass away from the optimum will divert energy from some other aspect of growth or behavior that has also been shaped by natural selection. We have seen that RE values for hatchery and wild females were remarkably similar in both 2001 and 2002.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

### **Acknowledgements**

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**Spawner and Redd Characteristics of Wild- and  
Hatchery-Origin  
Upper Yakima River Spring Chinook**

Prepared by:

Curtis M. Knudsen<sup>1</sup>, Brenda L. Ben-James<sup>2</sup>, Steve L. Schroder<sup>3</sup>,  
and Todd N. Pearsons<sup>4</sup>

<sup>1</sup> Oncorh Consulting, 2623 Galloway SE, Olympia, WA 98501

<sup>2</sup> Cascade Aquatics, Ellensburg, WA 98926

<sup>3</sup> Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501

<sup>4</sup> Ecological Interactions Team, WDFW, 201 N. Pearl Street, Ellensburg, WA 98926

## Abstract

In 2002, we monitored the in-river redd characteristics of naturally spawning upper Yakima River hatchery and wild females. We compared the selected spawning habitats in terms of water depth, velocity and substrate characteristics; spatial and temporal spawning distribution; time to construct and guard redds; redd size parameters; and distance to the nearest contemporaneously spawning female. Redds were sampled by snorkeling 3 to 4 days per week between September 9 and October 2 and were associated with a female of known origin identified by the presence (wild) or absence (hatchery) of the female's adipose fin. During each observation, female size was estimated visually and redd status and behavioral stage of females noted. After spawning was completed, a suite of redd width, length, depth, velocity and substrate parameters were collected from each known-origin redd.

A total of 76 hatchery- and 43 wild-origin females and associated redds were monitored. Naturally spawning hatchery females were significantly smaller than wild females by 1.7 cm on average. In our initial analyses of redd parameter data there were no significant differences in either redd width or length dimensions, water depths, velocities or substrate characteristics between hatchery- and wild-origin females ( $p > 0.45$ ). Most redd characteristics were not correlated with female length and in the 8 significant correlations out of 44, female length only explained between 6 and 20% of the total variation. Mean water velocity was 0.6-0.7 m/sec and mean depth associated with redds was 0.4 m. Both hatchery and wild females preferred spawn habitat in the pool/riffle transition zone. We will use this data to examine sample size needs and sampling effort for next year's work.

All findings in this report should be considered preliminary and subject to further revision unless previously published in a peer-reviewed technical journal.

## Introduction

Within the area of Reproductive Success, a critical concern is the *in situ* reproductive behavior of naturally spawning hatchery returns compared to their wild counterparts. We are interested in whether hatchery origin fish have the same temporal spawning distribution, the same spatial and temporal distribution within a given river reach, take the same time to construct and guard individual redds, utilize the same types of spawning habitat as wild origin fish and are their redds comparable in size. To address these issues requires more intensive monitoring of in-river spawners than the weekly spawning ground carcass surveys the project has historically performed. Significant changes in locally adapted traits due to hatchery influences will likely be maladaptive and result in reduced population productivity and fitness (Taylor 1991; Hard 1995). Naturally spawning hatchery fish have been shown to be less reproductively successful than wild fish in some studies (Resenbichler and McIntyre 1977; Chilcote et al. 1986; Leider et al. 1990) particularly in populations that have experienced multiple years of domestication (see review in Schroder et al. 2002).

In the following chapter, we describe the initial work done in 2002 and make comparisons between naturally spawning hatchery origin fish from the Cle Elum Supplementation Research Facility (CESRF) and upper Yakima River wild origin spring chinook returning in 2002 over a suite of redd characteristics.

## Methods and Materials

The study area is located in the upper Yakima River beginning just downstream of Easton Dam and extended downstream to the Eatson spring chinook Acclimation Site. Redds were sampled by snorkeling 3 to 4 days per week between Sept. 9 and Oct. 2, 2002. Females were identified to origin based in the presence (wild) or absence (hatchery) of their adipose fin. All spring chinook released from the Cle Elum Supplementation and Research Facility (CESRF) are adipose fin clipped. During each survey a female's length was estimated visually and the status of her redd and behavioral stage was noted. Behavioral stages were classified as: New - test dig/female staging/newly moved substrate present, Constructing - redd in progress with one or more adults males attending, female digging but not spent, Completed - no attending males, female spent and guarding or absent. Female behavior was characterized as: Staging - Female/male present, no well established redd yet, Constructing - Still in spawning stage, actively digging, female attended by 1 or more males, Guarding - Spent female on a completed redd, no attending males, and Empty - Fish absent. Male origin was noted when possible.

After spawning was completed and redd construction was finished, a suite of characters were collected from each known origin redd (Fig. 1). Redds were characterized by physical dimensions (max width and length, bowl length, and tail

length), water depth and velocity (at each point length measurements were taken from). Water temperature was taken during each survey. A visual assessment of substrate characteristics were made by estimating the percent sand, gravel, cobble and boulder. Redd habitat types were given an ordinal score: riffle=1, riffle/pool transition=2, pool=3, pool/glide=4, and glide=5. Water velocity measurements were taken at 0.6 depth. The distance to nearest contemporaneous redd was also measured. That is, the distance to the nearest redd occupied by an actively digging or guarding female. A total of 76 hatchery- and 43 wild-origin redds were monitored in 2002. In addition, total river discharge was measured on three occasions at the Easton Acclimation Site to monitor how much the hydrograph changed over the survey period.

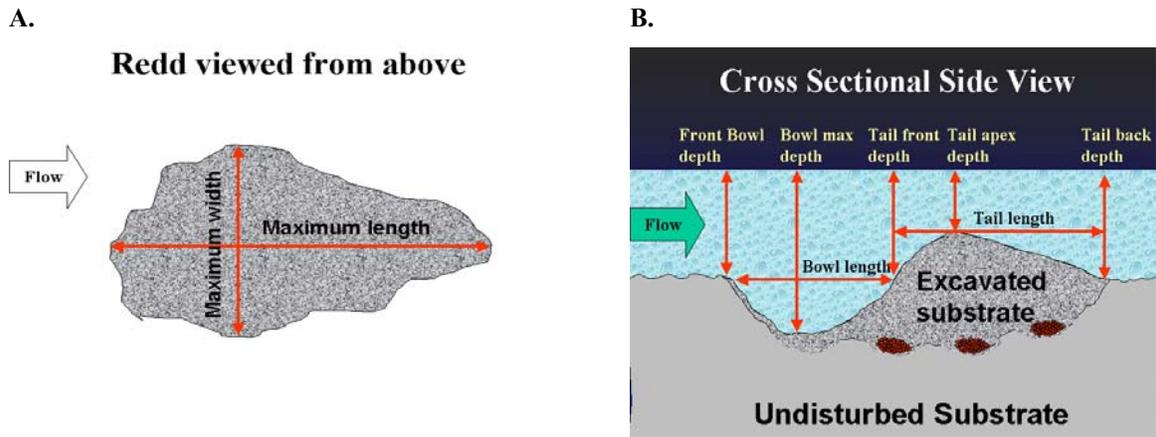


Figure 1. A redd as viewed from above (A) and from the side (B) showing the parameters measured. Water velocities were measured at each point a depth measurement was collected.

All comparisons were done using 1-way ANOVA. The percentage substrate variables were arc sin transformed prior to analyses. The SYSTAT 8.0 software package was used to perform all regression and ANOVAs (SPSS 1998).

## Results

We averaged the visual length estimates for a female made during the surveys and used that average to represent each female's length in the analyses below. Mean hatchery and wild female lengths were 69.6 and 71.3 cm, respectively. Wild female lengths were significantly longer than hatchery females (Tables 1 and 2).

| Table 1. Estimated mean length of Hatchery and Wild origin females based on multiple visual observations during snorkel surveys. |           |     |    |      |
|--|-----------|-----|----|------|
| Origin   | Mean (cm) | Sd  | n  | cv   |
| Hatchery   | 69.6      | 3.6 | 76 | 5.2% |
| Wild   | 71.3      | 2.5 | 43 | 3.5% |

| Table 2. One-way ANOVA results comparing visually estimated female lengths testing for Origin (Hatchery/Wild) effects. |         |     |       |         |         |
|--|---------|-----|-------|---------|---------|
| Source   | SSq     | df  | MSq   | F-ratio | P-value |
| Origin   | 73.16   | 1   | 73.16 | 6.98    | 0.009   |
| Error  | 1226.14 | 117 | 10.48 |         |         |

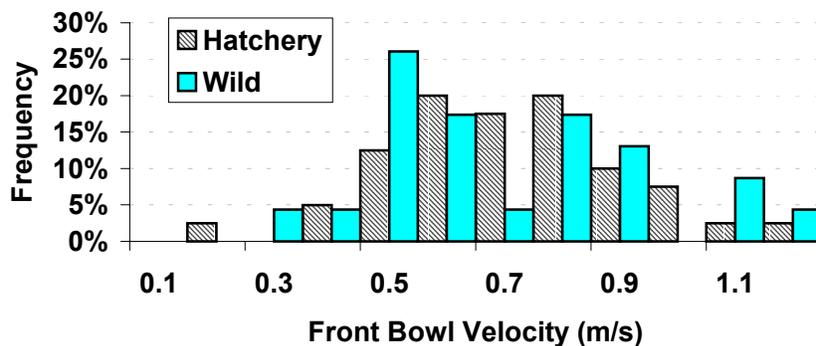


Figure 2. Frequency distribution of front bowl velocities (m/sec). Hatchery mean=0.676 and wild mean=0.684; ANOVA  $p=0.865$ .

The frequency distributions of water velocity at the front of the bowl are shown in Figure 2 and illustrate the large overlap observed in all velocities measurements between hatchery and wild redds. Mean water velocities within redds ranged from 0.65-0.74 m/sec for hatchery and 0.64-0.73 m/sec for wild redds (Fig. 3). Mean water depths at the margins of redds ranged from 0.36-0.39 m and 0.36-0.41 m for hatchery and wild redds,

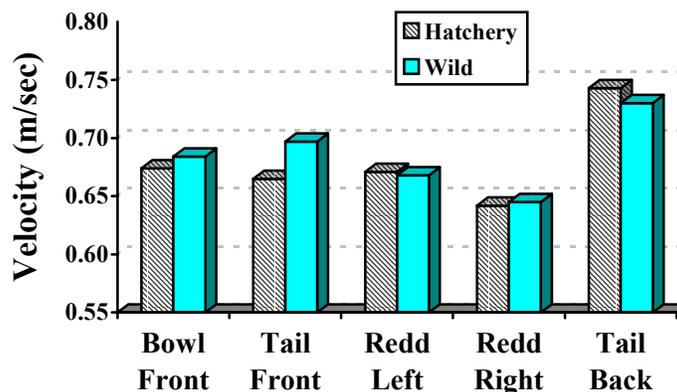
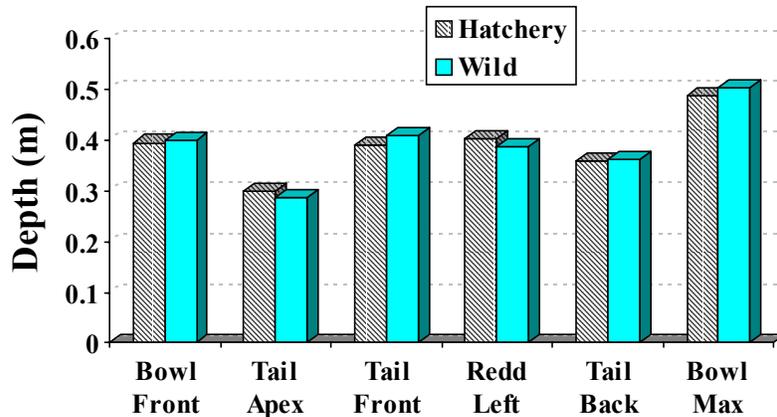


Figure 3. Mean velocities at various points within the redd. Each velocity measurement was taken at a point where a redd width, length or depth measurement was collected (see Figure 1).

respectively, (Fig. 4). In general, wild redd width and length means were slightly larger than hatchery redds, although in no case was this difference statistically significant. Average maximum redd width was 2.62 m for hatchery and 2.67 m for wild redds, while average maximum redd length was 5.18 m for hatchery and 5.25 m for wild redds. Mean maximum bowl length was 2.00 m for hatchery and 2.12 m for wild redds and tail lengths were 3.14 and 3.11 m for hatchery and wild redds, respectively. There were no significant differences in any of the redd characteristics we analyzed (Table 3).



**Figure 4. Mean depth at various redd locations for females of hatchery and wild origin. Each depth measurement was taken at a point where a redd width or length measurement was collected (see Figure 1) accept the bowl and apex depths.**

The average redd habitat score was 4.4 and 4.3 for hatchery and wild redds indicating both groups preferred to spawn in the riffle/glide transition zone. During the surveys, water temperature ranged from 10 to 16°C and averaged 12.9°C. Total river discharge at the Easton acclimation site during the survey period ranged from 4.9 to 5.5 m<sup>3</sup>/sec.

Female length was regressed against the redd characteristics to estimate to what extent female size was a significant contributor to redd parameter variation (Table 4). Hatchery and wild females were analyzed separately. In only 8 regressions was female length a significant factor, and in those cases only 6 to 20% of the total trait variation was explained by female size.

| Table 3. One-ANOVA results comparing hatchery and wild redd characteristics. |        |     |       |         |         |
|--|--------|-----|-------|---------|---------|
| Source/Character   | SSq    | df  | MSq   | F-ratio | P-value |
| Habitat type   | 0.56   | 1   | 0.56  | 0.75    | 0.390   |
| Error  | 75.15  | 101 | 0.74  |         |         |
| Front bowl depth   | 0.01   | 1   | 0.01  | 0.25    | 0.616   |
| Error  | 1.98   | 101 | 0.02  |         |         |
| Front bowl velocity  | 0.01   | 1   | 0.01  | 0.15    | 0.696   |
| Error  | 4.71   | 101 | 0.05  |         |         |
| Front tail depth   | 0.01   | 1   | 0.01  | 0.864   | 0.355   |
| Error  | 1.66   | 101 | 0.02  |         |         |
| Front tail velocity  | <0.01  | 1   | <0.01 | 0.01    | 0.915   |
| Error  | 5.02   | 101 | 0.05  |         |         |
| Left redd depth  | <0.01  | 1   | <0.01 | 0.016   | 0.899   |
| Error  | 2.27   | 101 | 0.02  |         |         |
| Left redd velocity   | <0.01  | 1   | <0.01 | 0.07    | 0.795   |
| Error  | 5.240  | 101 | 0.05  |         |         |
| Right redd depth   | 0.02   | 1   | 0.02  | 0.81    | 0.371   |
| Error  | 2.19   | 101 | 0.02  |         |         |
| Right redd velocity  | <0.01  | 1   | <0.01 | 0.05    | 0.829   |
| Error  | 7.38   | 101 | 0.07  |         |         |
| Back tail velocity   | <0.01  | 1   | <0.01 | 0.01    | 0.933   |
| Error  | 6.60   | 101 | 0.07  |         |         |
| Maximum redd length  | 0.10   | 1   | 0.10  | 0.05    | 0.827   |
| Error  | 210.43 | 101 | 2.08  |         |         |
| Maximum redd width   | 0.05   | 1   | 0.05  | 0.09    | 0.765   |
| Error  | 58.53  | 101 | 0.58  |         |         |
| Bowl length  | 0.34   | 1   | 0.34  | 0.46    | 0.499   |
| Error  | 74.77  | 101 | 0.74  |         |         |
| Tail length  | 0.03   | 1   | 0.03  | 0.02    | 0.882   |
| Error  | 131.91 | 101 | 1.31  |         |         |
| Distance to left bank  | 0.18   | 1   | 0.18  | <0.01   | 0.961   |
| Error  | 7714.1 | 101 | 76.38 |         |         |
| Distance right bank  | 3.23   | 1   | 3.23  | 0.06    | 0.811   |
| Error  | 5664.7 | 101 | 56.06 |         |         |
| Distance to left bank  | 1.35   | 1   | 1.35  | 0.02    | 0.878   |
| Error  | 5768.3 | 101 | 57.11 |         |         |

| Table 4. Linear regression results of female length versus the listed redd character by Origin (Hatchery/Wild). |          |    |                     |          |             |                            |
|---|----------|----|---------------------|----------|-------------|----------------------------|
| Redd Character  | Origin   | n  | Adj. R <sup>2</sup> | Constant | Coefficient | Regression <i>p</i> -value |
| Bowl front depth  | Wild     | 43 | 0.021               | -0.050   | 0.001       | 0.111                      |
|   | Hatchery | 76 | 0.020               | -0.627   | 0.014       | 0.183                      |
| Estimated redd area   | Wild     | 43 | 0.000               | -72.92   | 1.710       | 0.364                      |
|   | Hatchery | 76 | 0.000               | 45.51    | 0.003       | 0.997                      |
| Front bowl velocity   | Wild     | 43 | 0.081               | -1.402   | 0.029       | *0.036                     |
|   | Hatchery | 76 | 0.000               | 0.172    | 0.007       | 0.339                      |
| Maximum bowl depth  | Wild     | 42 | 0.026               | -0.552   | 0.015       | 0.157                      |
|   | Hatchery | 63 | 0.000               | 0.357    | 0.002       | 0.702                      |
| Tail apex depth   | Wild     | 42 | 0.003               | -0.559   | 0.012       | 0.295                      |
|   | Hatchery | 63 | 0.000               | 0.532    | -0.003      | 0.526                      |
| Front tail depth  | Wild     | 43 | 0.014               | -0.477   | 0.012       | 0.212                      |
|   | Hatchery | 76 | 0.000               | 0.489    | -0.001      | 0.701                      |
| Tail surface velocity   | Wild     | 41 | 0.001               | -0.507   | 0.018       | 0.314                      |
|   | Hatchery | 72 | 0.081               | -0.921   | 0.024       | *0.009                     |
| Front tail velocity   | Wild     | 43 | 0.133               | -2.377   | 0.043       | *0.009                     |
|   | Hatchery | 76 | 0.020               | -0.121   | 0.011       | 0.117                      |
| Left redd velocity  | Wild     | 43 | 0.000               | -0.076   | 0.010       | 0.494                      |
|   | Hatchery | 75 | 0.013               | -0.077   | 0.011       | 0.162                      |
| Back tail velocity  | Wild     | 43 | 0.204               | -3.105   | 0.054       | *0.001                     |
|   | Hatchery | 76 | 0.019               | -0.215   | 0.014       | 0.124                      |
| Redd maximum length   | Wild     | 43 | 0.000               | 4.004    | 0.018       | 0.865                      |
|   | Hatchery | 76 | 0.000               | 4.576    | 0.009       | 0.853                      |
| Redd maximum width  | Wild     | 43 | 0.048               | -6.100   | 0.126       | 0.085                      |
|   | Hatchery | 76 | 0.000               | 3.677    | -0.014      | 0.556                      |
| Bowl length   | Wild     | 41 | 0.000               | 0.768    | 0.019       | 0.777                      |
|   | Hatchery | 72 | 0.000               | 1.784    | 0.003       | 0.897                      |
| Tail length   | Wild     | 41 | 0.000               | -0.813   | 0.056       | 0.434                      |
|   | Hatchery | 72 | 0.000               | 2.827    | 0.005       | 0.909                      |
| Bowl % sand   | Wild     | 40 | 0.000               | 0.547    | -0.005      | 0.485                      |
|   | Hatchery | 63 | 0.060               | 0.856    | -0.010      | *0.029                     |
| Bowl % gravel   | Wild     | 40 | 0.000               | 0.487    | -0.004      | 0.590                      |
|   | Hatchery | 63 | 0.000               | 0.200    | <-0.001     | 0.983                      |
| Bowl % cobble   | Wild     | 40 | 0.000               | 0.178    | 0.002       | 0.888                      |
|   | Hatchery | 63 | 0.000               | 0.585    | -0.004      | 0.549                      |
| Bowl % boulder  | Wild     | 40 | 0.000               | -0.222   | 0.008       | 0.539                      |
|   | Hatchery | 63 | 0.015               | -0.467   | 0.011       | 0.171                      |

| Table 4 cont'd. Results from linear regressions of female length versus the listed traits. |          |    |                     |          |             |                            |
|--|----------|----|---------------------|----------|-------------|----------------------------|
| Trait  | Origin   | n  | Adj. R <sup>2</sup> | Constant | Coefficient | Regression <i>p</i> -value |
| Tail % sand  | Wild     | 40 | 0.097               | -0.971   | 0.016       | *0.028                     |
|  | Hatchery | 63 | 0.047               | 0.581    | -0.006      | *0.048                     |
| Tail % gravel  | Wild     | 40 | 0.088               | 1.586    | -0.018      | *0.035                     |
|  | Hatchery | 63 | 0.000               | -0.110   | 0.006       | 0.338                      |
| Tail % cobble  | Wild     | 40 | 0.018               | 1.443    | -0.015      | 0.198                      |
|  | Hatchery | 63 | 0.000               | 0.351    | 0.001       | 0.876                      |
| Tail % boulder   | Wild     | 40 | 0.066               | -1.070   | 0.018       | 0.060                      |
|  | Hatchery | 63 | 0.000               | 0.161    | <-0.001     | 0.978                      |

## Discussion

The estimated difference in the mean lengths of the surveyed hatchery and wild females was just under 2 cm and equals the length difference between age-4 hatchery and wild females observed in Chapter 1. Thus, the fish monitored appear to be representative of the hatchery and wild populations naturally spawning in the upper Yakima River in 2002. However, we did not detect any significant differences between the hatchery and wild redd characteristics we monitored. This is not surprising, given that few of the redd characteristics we monitored were significantly correlated with female size, and the few that were correlated explained  $\leq 20\%$  of the total trait's variation.

In 2003 we will monitor redds made by naturally spawning fish in the reproductive success spawning channel at CESRF and compare them to in-river redds. This comparison will help us determine if the spawning channel's velocities and depths are representative of in-river spawning sites and are fish spawning in the CESRF channel constructing redds with similar characteristics to those in the wild.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal.

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